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Electrical and Electronic Components in Motor Vehicles up to 3,5 t

General Requirements, Test Conditions, and Tests

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Changes

The following changes have been made to VW 80000: 2021-07:

- a) Error corrected in section 4.14.2.2: table 7 changed („with $T_{cool} = T_{RT}$ “ added)
- b) Error corrected in section 5.4.5.2: „Number of DUTs“ changed to „Number of cycles“
- c) Error corrected in section 5.4.5.3: „Number of DUTs“ changed to „Number of cycles“
- d) Error corrected in section 5.4.8.2, test case 4: „30 Hz – 200 kHz“ changed to „30 kHz – 200 kHz“
- e) Error corrected in section 5.4.13.2.2: „Test pulse“ changed to „Test sequence“
- f) Error corrected in section 5.4.13.3: „Test case 1 – hot start“ changed to „Test case 2 – hot start“
- g) Error corrected in section 5.4.15.2: figure 17 revised
- h) Error corrected in section 5.4.18.2: Table title adapted
- i) Error correction section 5.5.4.2: „superimposed with“ added in table 48 and legend of figure 26 adapted
- j) Error corrected in section 5.6.7.2: Title of figure 36 adapted
- k) Error corrected in section 5.6.15.2: figure 41 revised, legend of figure 43 adapted, and table 79 changed (T [water bath] changed from „75“ to „70“)
- l) Error corrected in section 5.6.16.2: „Na“ test added
- m) Editorial change in section 5.6.16.3
- n) Error corrected in section 5.7.1.2: „DIN 51625“ changed to „DIN EN 15293“
- o) Error corrected: „DIN EN 60068-2-11“ changed to „DIN EN IEC 60068-2-11“
- p) Error corrected in section F.1: table F.1 changed (ambient humidity from „60%“ to „65%“)
- q) „Appendix G“ and references to it deleted

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1 Scope

This document defines the requirements, test conditions and tests for electrical, electronic and mechatronic components and systems to be used in motor vehicles up to 3,5 t.

The tests shown are used to test a part of the component's required properties and are not used to qualify electrical/electronic subcomponents or to qualify the manufacturing process.

2 Definitions

Application software

Refers to behavior in relation to this function class as per this standard and functionalities as per the Performance Specification, for instance: start-up behavior, sleep behavior, control systems, overload, short circuit and fiddle-proof systems and diagnostic systems

Assembly

Electronic circuit carrier fitted with subcomponents (without housing)

Charging

Operating situation of a vehicle with an electric drive that is parked and connected to a charging station/socket-outlet. The high-voltage (HV) energy store is charged.

Climatic chamber with condensation option

A specially controlled water bath in the climatic chamber, by means of which the required water quantity is implemented in the form of water vapor. The intensity of the condensation film on the circuit carrier depends on the thermal capacity, the relative humidity, and the temperature gradient of the water bath. The climate control of the climatic chamber is switched off during the condensation phase. The test chamber temperature is controlled by means of the temperature-controlled water bath.

Component

A full component, electronic control unit or mechatronic control module (with housing)

Derating

Deliberately limited function, e.g., change in power consumption as a function of voltage or temperature

Device under test

The system or component to be tested

Driving

Operating situation of a vehicle that has been released and put into operation by the customer (terminal 15 (t.15) on). A vehicle with an electric drive is not connected to a charging station/outlet.

Field

Describes the use of the vehicle or of the component in customer operation under real conditions

Functions

Includes system-specific and diagnostic functions

Functions that are relevant for a cold start

Functions that are required during the internal combustion engine (ICE) cold-start procedure or that need to meet functional state A. For example, these may be as follows: **1.** Partial functions in the engine control module, the starter relay, the starter, the clutch switch or the interlock **2.** To maintain the energy supply to relevant functions during the ICE cold-start procedure (e.g., DC/DC converter,

backup batteries, Q diode). **3. Functions** that need to meet functional state A during the ICE cold-start procedure. These functions are defined by the purchaser using the classification in function class 1 as per table 1.

Hardware freeze

The point during development from which changes to the hardware are no longer possible

High voltage

Voltage range of 60 V_{DC} to 1 500 V_{DC} or 30 V_{AC} to 1 000 V_{AC}

Hot start (restart)

All start variants where the voltage V_{op} remains within the limits defined in E-11 Test case 2 - Hot start. A hot start may occur at any vehicle speed.

ICE cold start (initial start)

All start variants where the voltage V_{op} can reach down to the limits defined in E-11 Test case 1 - Cold start. The ICE cold start is split into the following phases: **1. ICE cold-start preparation: functions** that are required to release the ICE cold-start procedure. However, these functions are not necessarily required for the ICE cold-start procedure (e.g., key detection). **2. The ICE cold-start procedure:** starter activation period when the engine is undergoing a cold start, this is signalled by t.50. As far as the tests in this document are concerned, a cold start is only carried out when the vehicle is stationary. This may need to be taken into account when defining the operating mode of the device under test (DUT).

Operation (general)

Out of all relevant situations, operating situation in which minimum or maximum self-heating is generated. This operating situation is additionally defined.

Parking

Operating situation of a vehicle that is parked. A vehicle with an electrified drive can be connected to a charging station/socket-outlet, but the vehicle battery is not charged.

Preconditioning

Operating situation of a vehicle with an electric drive that is parked and can be connected to a charging station/socket-outlet. The vehicle executes thermal conditioning. This typically relates to a preconditioning of the vehicle interior or to a preconditioning of the HV battery.

Short circuit

A short circuit is defined by a load case with lower impedance than with the specified load, down to the limit case of 0 Ω. In this case, this includes a short circuit with a current just below the short circuit detection limit. A short circuit may be permanently present.

Standard tolerances

See section 4.16.

Subcomponent

Electrical, electronic, or mechatronic subcomponent (e.g., resistor, capacitor, transistor, integrated circuit [IC], relay)

System

Components that are linked by their functions, e.g., the brake control system (electronic control unit, hydraulic system, sensors)

3 Abbreviations

ASIL	Automotive Safety Integrity Level
CAN	Controller Area Network (communication bus system)
CC	Coolant circuit
DAE	Venting element
DUT	See Device under test
GND	The ground potential provided by the component , e.g., for sensors or actuators
HV	Index or designation for the high-voltage vehicle electrical system
H_{rel}	Air humidity, 25% to 75% relative humidity (standard value unless otherwise specified)
I_N	Nominal current
LCD	Liquid Crystal Display
PSD	Power Spectral Density
PTB	The National Metrology Institute of Germany (Physikalisch-Technische Bundesanstalt)
T_{RT}	Room temperature (23 ± 5) °C (standard value unless otherwise specified)
T_{cool}	Coolant feed temperature
$T_{cool,max}$	Max. coolant feed temperature
$T_{cool,min}$	Min. coolant feed temperature
T_{max}	Maximum ambient temperature
T_{min}	Minimum ambient temperature
$T_{op,max}$	Maximum ambient temperature for components with overload protection/overtemperature protection at which full functionality is still required
$T_{op,min}$	Minimum ambient temperature for components with overload protection/low-temperature protection at which full functionality is still required
T_{test}	The test temperature is equivalent to T_{RT} (standard value unless otherwise specified)
$V_{N,HV}$	HV nominal voltage/ HV standard voltage - HV_{DC} standard voltage
V_{PP}	Peak-to-peak voltage value
V_{RMS}	RMS value of a voltage
V_{max}	Maximum voltage that can occur during a test
V_{min}	Minimum voltage that can occur during a test
V_{op}	Static operating voltage for the 14-V test (standard value unless otherwise specified)
$V_{op,HV}$	HV operating voltage during a test - HV_{DC} operating voltage
V_{opmax}	Upper limit of the static operating voltage range for functional state A of a function (see table 1)
$V_{opmax,HV}$	Max. HV operating voltage - upper HV_{DC} operating voltage limit
V_{opmin}	Lower limit of the static operating voltage range for functional state A of a function (see table 1)
$V_{opmin,HV}$	Minimum HV operating voltage - lower HV_{DC} operating voltage limit
V_{test}	Test voltage
f	Frequency
t_f	Fall time (e.g., of a voltage curve)
$t_{operation}$	Entire operating duration observed over the component's service life
t_r	Rise time (e.g., of a voltage curve)
μC	Microcontroller
ΔT_{field}	Average temperature difference of the ambient temperature of the component at its point of use during the service life in the field

4 General requirements

4.1 Requirements for test laboratories

The test laboratory must be organized and run as per DIN EN ISO/IEC 17025. All test equipment used for measuring must be calibrated as per DIN EN ISO/IEC 17025 (or as specified or recommended by the manufacturer) and it must be possible to trace the equipment back to the PTB or an equivalent national standards laboratory. The testing equipment, production equipment, installations and test methods used may not limit or distort the behavior of the DUT (i.e., by drawing current) These must be documented in the test report together with the accuracies and the expiration date of the calibration.

4.2 Test procedure

The electrical load must be implemented and operated using original loads unless otherwise specified.

No later than from the C-sample version, the DUT must be operated with application software during the test.

If the software package, application parameters, or processor utilization affects the test result, the affected tests must be repeated if these are changed.

The software version and level of functionality must be indicated in the test report.

The purchaser must approve the opening of DUTs, except for the physical analysis.

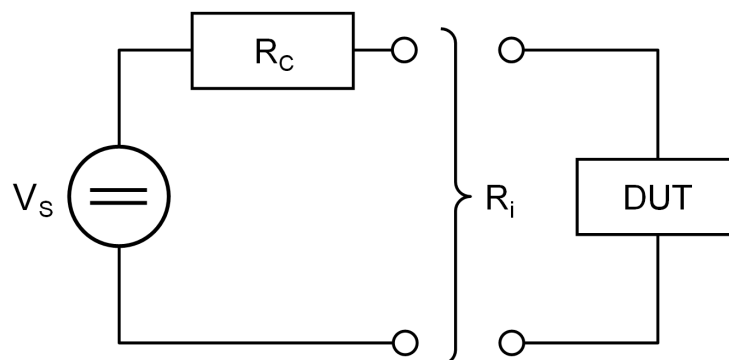
The key parameters must be monitored, recorded, and documented during each test. Resets of the component must be monitored in a suitable manner, and documented.

Before and after each test, the DUTs must be subjected to a P-02 parameter test (small) as per section 4.14.2. For environmental loads, the test is carried out within one hour after the test is complete.

4.3 Voltages and currents

The specified voltage curves must be interpreted as envelopes. Curves with any contour within the specified test and reference curves must be expected as the actual voltage curves.

All voltage and current specifications refer to the component (at its terminal). This does not apply to tests for which the internal resistance R_i is specified. In this case, the voltage and current specifications refer to the source (see figure 1).



Legend

V_s	Source
R_C	Cable resistance and contact resistance
R_i	Internal resistance observed at the terminals of the component in the direction of the source

Figure 1 – Internal resistance

All edge descriptions refer to the 10% or 90% voltage values.

4.4 Test voltages

Test voltages, particularly those for overvoltage and undervoltage tests, may significantly deviate from the static operating voltage ranges shown in section 4.3, and will be specified separately.

Functional state A (see section 4.8) must always be met within the static operating voltage range applicable to the **component**.

4.5 Sampling rates and measured-value resolutions

The sampling rate or bandwidth of the measuring system must be adapted to the DUT in question. All measured values must be recorded with all maximum values (peaks).

The resolution of the measured values must be adapted to the respective test. It must be ensured that voltage peaks do not lead to an overflow and that there will not be cases in which they cannot be measured due to insufficient resolution. Data reduction/abstraction (e.g., limit monitoring, bus-message evaluation) must not suppress irregularities.

4.6 Reaching a constant temperature throughout

A **component** exposed to a constant ambient temperature under defined operating conditions is considered to have reached a constant temperature throughout from the point in time that the temperature does not vary by more than ± 3 K at any point of the **component** over the course of time going forward.

The duration from when the ambient temperature change has ended, to when a constant temperature is reached throughout, must be determined by the purchaser and specified in the test documentation.

For temperature cycle tests, the **DUTs** must also be held at the specified temperature reference values for a defined period of time once they have reached a constant temperature throughout to

ensure that stresses in the component can be converted into elongations. This additional hold time must be indicated for the respective tests.

4.7 DUTs connected to a coolant circuit

In the case of components with a coolant circuit, the coolant temperature must track the respective test temperature to the limits $T_{cool,min}$ and $T_{cool,max}$. Only the ambient temperature is varied outside of the coolant temperature limits.

4.8 Functional states

4.8.1 General

This section describes the functional state of the DUT before, during, and after the test.

The purchaser defines the functional behavior (including derating, e.g., in terms of temperature and voltage) of the component in the functional states, as well as the customer's perception (e.g., visual, acoustic, tactile, thermal).

The memory functions must always remain in functional state A in all cases. The data integrity of the non-volatile memories must be ensured at all times. The time sequences of the functional states are specified by the purchaser. Permitted event memory entries must be agreed upon with the purchaser and must be recorded in writing.

Damage to the DUT is not permissible in functional states A to D. Undefined states are not permitted at any time. The permitted limit values specified in the datasheets (e.g., electrical, thermal, mechanical) for the electrical/electronic subcomponents installed in the DUT may not be exceeded. Proof of this must at least be provided by the P-02 parameter test (small) as per section 4.14.2.

Loose parts inside the unit are not permitted in functional states A to D. Proof must be provided by the physical analysis.

A manual shake test can be carried out as an intermediate test where possible to identify loose parts.

4.8.2 Functional state A

The DUT fulfills all functions as specified.

4.8.3 Functional state B

This functional state is not used.

4.8.4 Functional state C

The DUT does not fulfill one or more functions during exposure to the test parameters. After exposure to the test parameters, the DUT must immediately return to functional state A automatically or by means of the external triggers specified in the Performance Specification. Undefined functions are not permissible at any time.

4.8.5 Functional state D1

The DUT does not fulfill one or more functions during exposure to the test parameters. After exposure to the test parameters, the DUT must return to functional state A by switching the terminal off/on (with bus sleep, if required).

4.8.6 Functional state D2

The DUT does not fulfill one or more functions during exposure to the test parameters. After exposure to the test parameters, the DUT must return to functional state A via simple intervention (e.g., replacing a faulty fuse).

4.8.7 Functional state E

The DUT does not fulfill one or more functions during exposure to the test parameters and must be repaired or replaced after exposure to the test parameters.

The DUT may not auto-ignite at any time. The surface temperature of the DUT may not exceed the maximum value specified in the Performance Specification at any time.

For HV components, the basic requirements for HV safety (e.g. contact protection, insulation that is visibly undamaged) must be met by the DUT.

4.9 Function classes and operating voltage ranges

A DUT usually has several functions, which can each be allocated to different function classes. Function classes that are specific to the project can be defined for additional voltage parameters and test scopes (e.g., static operation up to 4,5 V)

NOTE 1: This standard does not provide any information on the reliability of the energy supply system and any voltages that may arise in relation to functional safety (ASIL).

Table 1 lists the functional states (A or C; see Section 4.8) required for each of the function classes.

Table 1 – Function classes and operating voltage ranges

Voltage range in V	Test	Duration	Function class					
			1	2	3	4	5	6
17 - 26	E-04 (Jump start)	≤ 60 s	C	C	C	C	C	C
16 - 17	E-01 (Long-term overvoltage)	≤ 1 h	A	A	A	C	C	A
18 - 27	E-05 (Load dump)	≤ 300 ms	A	A	A	C	C	A
16 - 18	E-02 (Transient overvoltage)	See E-02	A	A	A	A	A	A
9,8 - 16	Static operating voltage range		A	A	A	A	A	_a)
9 - 9,8	Static operating voltage range		A	A	C	A	C	_a)
6 - 9	Static operating voltage range		A	C	C	C	C	_a)
0 - 6	Static operating voltage range		C	C	C	C	C	_a)
≥ 9	E-03a (Transient undervoltage)	500 ms	A	A	A	A	A	A
≥ 7	E-11 (Hot start)	See E-11	A	A	A	A	C	A
≥ 6	E-03b (transient undervoltage)	See E-03b	A	A	A	C	C	A
≥ 4,5	E-11, normal (Cold start)	See E-11	A	C	C	C	C	C
≥ 3,2	E-11, severe (Cold start)	See E-11	A	C	C	C	C	C
≥ 0	E-10 (Brief interruptions)	≤ 100 μs	A	A	A	A	A	A
≥ 0	E-10 (Brief interruptions)	> 100 μs	C	C	C	C	C	C

a) The static operating voltage range is defined in the relevant Group Bus Performance Specification.

Minimum requirement for the use of the function classes:

- Function class 1: Functions that are relevant for a cold start or functions that are required to maintain the energy supply
- Function class 2: At least the ASIL A requirements as per ISO 26262 (all parts)¹⁾ apply to the electrical energy supply system of a function, or the function is defined as relevant to limp-home mode.
- Function class 3: Functions that are not classified in one of the function classes 1, 2, 4, 5, 6 or in a function class that is relevant to the project
- Function class 4: Functions that must be retained during „Engine off“ or „Vehicle electrical system supply only from store“

¹⁾ ISO 26262-1, ISO 26262-2, ISO 26262-3, ISO 26262-4, ISO 26262-5, ISO 26262-6, ISO 26262-7, ISO 26262-8, ISO 26262-9, ISO 26262-10, ISO 26262-11, ISO 26262-12

Function class 5: Functions that need to be available when the vehicle electrical system supply is active (supplying the 12-V energy network via a 12-V alternator or a DC/DC converter)

Function class 6: Bus communication²⁾

4.10 Operating situations

Operation of a component can usually be split into the following operating situations:

- Driving
- Charging
- Preconditioning
- Parking

All operating situations relevant to the component must be taken into account when deriving the operating modes and test requirements.

4.11 Operating modes

4.11.1 General

Details concerning the operating modes, operating loads (e.g., activation, bus activity, bus messages, original sensors, original actuators, equivalent circuits), and the required boundary conditions must be agreed upon between the contractor and the purchaser and must be documented.

If other operating modes are relevant to the component, they must be determined along with the purchaser.

The validation of the component requires operating modes that refer to the DUT not connected to the vehicle electrical system or to the DUT connected to the vehicle electrical system in a way that differs from the normal application environment.

4.11.2 Operating modes for validation

4.11.2.1 Operating mode I.a

The connectors and the wiring harness are not connected to the DUT. Any coolant hoses or pipes or other media circuits are not connected, and their connections are sealed.

4.11.2.2 Operating mode I.b

The connectors and the wiring harness are connected to the DUT, but they are not live. Any coolant hoses or pipes or other media circuits are connected.

4.11.2.3 Operating mode I.c

The connectors and the wiring harness are connected to the DUT. The vehicle electrical system and the coolant/other media circuits are connected in a way that deviates from the vehicle operating and application environment in accordance with the requirements of the respective test.

²⁾ The static operating voltage range is defined in the relevant Group Bus Performance Specification.

4.11.3 Operating modes for real operating loads

The following operating modes have been defined for the operating situations defined in section 4.10 to be able to simulate the various realistic loads on the component during the tests.

In contrast to the operating situations, the operating modes for real operating loads have been expanded with the „min“ or „max“ index.

The following applies to all operating modes for real operating loads:

- All electrical lines are connected to the DUT.
- Any coolant or other media circuits are filled, and the hoses or pipes are connected. Media flow, pressure and temperature must be set as specified in the Performance Specification if required.

4.11.4 Operating modes for low operating loads - min index

The DUT must be operated with the lowest possible operating load.

The following operating modes are used for tests:

- Driving_{min}
- Charging_{min}
- Preconditioning_{min}
- Parking_{min}

Out of these operating modes with low operating load, the operating mode during which the component generates the least power loss must be determined. This is defined in addition to the other operating modes, and referred to as:

- Operation_{min}

4.11.5 Operating modes for high operating loads - max index

The DUT must be operated with maximum operating load. If available, a defined load profile must be taken into account for maximum operating load. The load profile must be agreed upon with the purchaser for each test.

The following operating modes are used for tests:

- Driving_{max}
- Charging_{max}
- Preconditioning_{max}
- Parking_{max}

Out of these operating modes with high operating load, the operating mode during which the component generates the greatest power loss must be determined. This is defined in addition to the other operating modes, and referred to as:

- Operation_{max}

4.11.6 Overview of operating modes

All operating modes for the respective component (see table 2 for an overview) must be determined prior to the start of the test and agreed upon with the purchaser.

Table 2 – Overview of operating modes

Operating situation	Operating modes for validation	Operating modes for low operating loads	Operating modes for high operating loads
	I.a I.b I.c	Operation _{min}	Operation _{max}
Driving:		Driving _{min}	Driving _{max}
Charging:		Charging _{min}	Charging _{max}
Preconditioning:		Preconditioning _{min}	Preconditioning _{max}
Parking:		Parking _{min}	Parking _{max}

4.11.7 Application of the operating modes

Table 3 shows examples of how to apply operating modes to components in the vehicle.

Table 3 – Examples of operating modes

Operating mode	Radio with navigation system	Light control unit	Onboard charger
Operation _{min}	Parking _{min}	Parking _{min}	Parking _{min}
Operation _{max}	Driving _{max} /Parking _{max}	Component is active with cycle of operation for maximum power loss	Charging _{max}
Driving _{min}	Component switched off by the driver, data buses and μ Cs are active	Components active, daytime running light has been switched on	12-V level (data buses and μ Cs) is active, HV _{DC} is on, if required, no charging
Driving _{max}	Component is switched on (data buses, drives, navigation system, output stages are active)	Component active with a specified typical cycle of operation	12-V level (data buses and μ Cs) is active, HV _{DC} is on, if required, no charging
Charging _{min}	Not relevant	Not relevant	Component active on all voltage levels, charging with minimum charging capacity
Charging _{max}			Component active on all voltage levels, charging with maximum charging capacity
Preconditioning _{min}			12-V level (data buses and μ Cs) is active, HV _{DC} is on, if required, no charging
Preconditioning _{max}			Component active on all voltage levels, HV _{DC} vehicle electrical system supply with a specified power

Table 3 (continued)

Operating mode	Radio with navigation system	Light control unit	Onboard charger
Parking _{min}	Component in sleep mode, post-run ended	Component in sleep mode, post-run ended	Component in sleep mode, post-run ended, cyclic test for charge requirement, if needed
Parking _{max}	Component is switched on (data buses, drives, navigation system, output stages are active)	Component active with a specified typical cycle of operation	12-V level (data buses, μ Cs and activation of vehicle inlet) active, waiting for charge requirement

4.11.8 Service life requirements

Table 4 shows the typical parameters for service life requirements.

Table 4 – Typical service life requirements

Service life	15 years
Mileage	300 000 km
Driving operating duration	8 000 h
Charging operating duration	a)
Preconditioning operating duration	a)
Parking operating duration	a)
a) Defined in the Performance Specification specifically for each component	

4.11.9 Temperature load spectra

In order to describe the temperature load that a component is exposed to at the vehicle point of use, the minimum temperature T_{\min} and the maximum ambient temperature T_{\max} must be specified in addition to the distribution that indicates how long the component has been exposed to the various temperatures between T_{\min} and T_{\max} .

For vehicles with alternative drives, a distinction must be made between the driving, charging, preconditioning, and parking operating situations, and the respective temperature load spectra must be specified both for the ambient temperature and the coolant circuit temperature.

As a rule, this temperature distribution is a continuous distribution as the ambient temperature of the component can assume any value between T_{\min} and T_{\max} .

This continuous distribution can be adequately explained by a few discreet temperature data points $T_{\text{field},i}$ to design the component and to simplify the test duration calculation using the accelerated service life model as per Arrhenius (see appendix D). For each temperature data point, the percentage share p_i of the operating duration during which the component is exposed to the data point temperature must be specified.

Therefore, the respective temperature load spectrum has the general shape as per table 5, and is essentially based on field measurements and technical experience.

Table 5 – Temperature load spectrum

Temperature in °C	Distribution
$T_{\text{field},1} = T_{\text{min}}$	p_1
$T_{\text{field},2}$	p_2
...	...
$T_{\text{field},n} = T_{\text{max}}$	p_n

Typical temperature load spectra for Driving operating situation in terms of different installation areas are indicated in appendix B.

The ability of these typical temperature load spectra to be used for a specific component must be verified, e.g., by vehicle measurement, simulation, or experience. In case of deviations, the temperature load spectrum must be adapted to the particular component.

A component-specific temperature load spectrum must be defined for special points of use or installed conditions (e.g., at a point of use near a heat source).

The applicable temperature load spectrum must be documented. In addition to the typical temperature load spectra, the typical values for an average temperature rise that a component experiences in the vehicle in driving operating situation are specified in appendix B.

This value must also be determined and documented in a way that is specific to each component for temperature load spectra that have been defined or adapted specifically for each component.

4.12 Key parameters and key functions

Key parameters and key functions to evaluate tests must be defined by the contractor subject to agreement with the purchaser for all tests.

The acceptance criteria for the key parameters and key functions must be defined by the contractor, subject to agreement with the purchaser. Proof that these parameters and functions comply with the acceptance criteria must be provided by the contractor in accordance with the test descriptions, and documented.

The key parameters to be recorded and monitored during a test depend on the type of test.

A subset of all key parameters and key functions can be defined for a test that has been specifically designed for the type of test.

The key parameters and key functions that are relevant to a parameter test depend on the previous and following test.

A subset of all key parameters and key functions can be defined for the P-01 parameter test (function check) and the P-02 parameter test (small) that has been specifically designed for the previous and following test.

The definition of subsets from all key parameters and key functions must be agreed upon with the purchaser.

Examples of key parameters and key functions:

Quiescent current draw, operating currents, internal supply voltages, output voltages, contact resistances, input impedances, signal rates (rise and fall times), frequency responses, limit leakage

rates, sensitivities, event memory parameters, audio parameters, optical properties, corrosion resistance, acoustic properties and surface properties

4.13 Interface description

The states and electrical properties of all interfaces must be fully described. This description is used as the basis for evaluating the test results and must be detailed accordingly.

4.14 Parameter tests

4.14.1 P-01 Parameter test (function check)

4.14.1.1 Purpose

The parameter tests must provide proof that the component is working properly for the specified test parameters (see table 6).

4.14.1.2 Test

The key parameters and key functions must be measured and documented.

A visual check must be carried out as per DIN EN 13018.

In the case of components with an event memory, the contents of the event memory must be read out and documented.

In the case of components with an HV supply system, the parameter tests must be carried out as follows:

1. at V_{opmin} , V_{op} , and at V_{opmax} with $V_{N,HV}$ in each case
2. at $V_{opmin,HV}$, $V_{N,HV}$ and at $V_{opmax,HV}$ with V_{op} in each case

The parameter tests must be carried out immediately after the previous tests have been completed.

The time between the end of the previous test and the parameter test procedure must be documented in the test report.

Table 6 – P-01 test parameters

T_{test}	T_{RT} with $T_{cool} = T_{RT}$ (unless otherwise specified, such as with K-02)
V_{test}	V_{opmin} , V_{op} , V_{opmax}
Key parameters and key functions	All of them, or a specific subset to be agreed upon

4.14.1.3 Requirement

Functional state A

All key parameters and key functions must meet the defined acceptance criteria.

4.14.2 P-02 Parameter test (small)

4.14.2.1 Purpose

The parameter tests must provide proof that the component is working properly for the specified test parameters (see table 7).

4.14.2.2 Test

The key parameters and key functions must be measured and documented.

A visual check must be carried out as per DIN EN 13018.

In the case of components with an event memory, the contents of the event memory must be read out and documented.

In the case of components with an HV supply system, the parameter tests must be carried out as follows:

3. at V_{opmin} , V_{op} , and at V_{opmax} with $V_{N,HV}$ in each case
4. at $V_{opmin,HV}$, $V_{N,HV}$ and at $V_{opmax,HV}$ with V_{op} in each case

The parameter tests must be carried out immediately after the previous tests have been completed.

The time between the end of the previous test and the parameter test procedure must be documented in the test report.

Table 7 – P-02 test parameters

T_{test}	T_{RT} where $T_{cool} = T_{RT}$
V_{test}	V_{op}
Key parameters and key functions	All of them, or a specific subset to be agreed upon

4.14.2.3 Requirement

Functional state A

All key parameters and key functions must meet the defined acceptance criteria.

4.14.3 P-03 Parameter test (large)

4.14.3.1 Purpose

The parameter tests must provide proof that the component is working properly for the specified test parameters (see table 8).

4.14.3.2 Test

The key parameters and key functions must be measured and documented.

A visual check must be carried out as per DIN EN 13018.

In the case of components with an event memory, the contents of the event memory must be read out and documented.

In the case of components with an HV supply system, the parameter tests must be carried out as follows:

5. at V_{opmin} , V_{op} , and at V_{opmax} with $V_{N,HV}$ in each case
6. at $V_{opmin,HV}$, $V_{N,HV}$ and at $V_{opmax,HV}$ with V_{op} in each case

The parameter tests must be carried out immediately after the previous tests have been completed.

The time between the end of the previous test and the parameter test procedure must be documented in the test report.

Table 8 – P-03 test parameters

T_{test}	T_{min} with $T_{cool,min}$ T_{RT} with $T_{cool} = T_{RT}$ T_{max} with $T_{cool,max}$
V_{test}	V_{opmin} , V_{op} , V_{opmax}
Key parameters and key functions	All

4.14.3.3 Requirement

Functional state A

All key parameters and key functions must meet the defined acceptance criteria.

4.14.4 P-04 Physical analysis

4.14.4.1 Purpose

The physical analysis must be carried out after each reliability testing phase (B-sample, C-sample, etc.) to identify changes to the component as compared to the unused condition.

4.14.4.2 Test

The physical analysis must be carried out as per VW 80005.

In addition, all DUTs must be opened and subjected to a visual inspection as per DIN EN 13018.

4.14.4.3 Requirement

The results must be documented and evaluated in the test report.

4.15 Continuous parameter monitoring with drift analysis

The key parameters must be recorded throughout the entire test.

For components with an event memory, the event memory must be monitored continuously and the entries must be documented.

The data obtained from continually monitoring the parameters must be examined for trends and drifts to detect any irregularities, aging, or malfunctions of the component.

The P-03 parameter test (large) as per section 4.14.3 must be carried out prior to the first and after the last test of a testing sequence.

The measurement results and data from the before/after tests may differ from each other only within the specified permissible tolerances. Changes in the measured values greater than the measurement accuracies must be highlighted. The measurement results must be examined for trends and drifts to detect any irregularities, aging, or malfunctions of the component.

4.16 Standard tolerances

Unless otherwise specified, the tolerances specified in table 9 apply.

The tolerances refer to the required measured value.

Table 9 – Standard tolerances

Frequencies	±1%
Temperatures	±2 °C
Humidity	±5%
Times	+5%; 0%
Voltages	±2%
Currents	±2%
Mechanical vibration/excitation	±3 dB
Vibration PSD	±5%

4.17 Standard values

Unless otherwise specified, the standard values in table 10 apply.

Table 10 – Standard values

Room temperature	$T_{RT} = 23\text{ °C} \pm 5\text{ °C}$
Humidity	$H_{rel} = 25\% \text{ to } 75\%$ relative humidity
Test temperature	$T_{test} = T_{RT}$
Operating voltage (for test)	$V_{op} = 14\text{ V}$

5 Requirements and tests

5.1 Test selection table for electrical tests

See table 11.

Table 11 – Test selection table for electrical tests

Test	Must be applied to	Required specifications
E-01 Long-term overvoltage	Components supplied via the 12-V vehicle electrical system	None
E-02 Transient overvoltage	Components supplied via the 12-V vehicle electrical system	None
E-03a Transient undervoltage	Components supplied via the 12-V vehicle electrical system	None
E-03b Transient undervoltage	Components supplied via the 12-V vehicle electrical system	None
E-04 Jump start	Components supplied via the 12-V vehicle electrical system	None
E-05 Load dump	Components in vehicles with a 12-V alternator	None
E-06 Ripple voltage	Test case 1 for all components, test cases 2 and 3 only for vehicles with a 12-V alternator, test case 4 only for vehicles with a DC/DC converter	Test cases
E-07 Slow decrease and increase of the supply voltage	All components	Relevant terminal status
E-08 Slow decrease, quick increase of the supply voltage	All components	Relevant terminal status
E-09 Reset behavior	All components	Relevant terminal status, test boundary conditions
E-10 Brief interruptions	All components	None
E-11 Start pulses	Components supplied via the 12-V vehicle electrical system; may not be applicable to vehicles without a 12-V starter	Applicability
E-12 Voltage curve with vehicle electrical system control	Components supplied via the 12-V vehicle electrical system	None
E-13 Pin interruption	All components	Relevant terminal status
E-14 Connector interruption	All components	None
E-15 Reverse polarity	Components supplied via the 12-V vehicle electrical system	Severity, test case
E-16 Ground potential difference	All components	None
E-17 Short circuit in signal cable and load circuits	Test case 1 - 3: all components Test case 4: GND cables with a cyclic bending load	Short circuit current and fuse time-current characteristic, if required

Table 11 (continued)

Test	Must be applied to	Required specifications
E-18 Insulation resistance	<ul style="list-style-type: none"> – 12-V circuits of components with insulation materials that are relevant for quiescent current – Motor windings – Relays 	Test points
E-19 Quiescent current	Components that are continuously supplied with voltage (e.g., t.30, t.30f, t.30g)	None
E-20 Dielectric strength	<ul style="list-style-type: none"> – 12-V circuits of components with insulation materials that are relevant for quiescent current – Motor windings – Relays 	Test points
E-21 Backfeeds	Components that are electrically connected to t. 15 or to other terminals with a wake-up function	None
E-22 Overcurrents	Components with an output	None
E-23 Equalizing currents of multiple supply voltages	Components supplied via an independent t.30	None
E-24 ON/OFF durability testing	All components	None

5.2 Test selection table for environmental tests

See table 12.

Table 12 – Test selection table for environmental tests

Test	Must be applied to	Required specifications
M-01 Free fall	<p>All components</p> <p>The test may be omitted for components that will obviously be damaged during the test (e.g., glass bodies, extremely sensitive transducers), subject to agreement with the purchaser. This must be documented.</p>	None
M-02 Stone impact test	Components installed in areas that may be affected by stone impact	None
M-03 Dust test	All components	IP degree of protection
Degree of protection IP6KX	Components for which the ingress of dust is not permissible	
Degree of protection IP5KX	Components for which the ingress of dust is permissible, but only as long as function and safety are not impaired	

Table 12 (continued)

Test	Must be applied to	Required specifications
M-04 Vibration test	All components	Vibration profile
As per vibration profile A	Components installed on the engine/motor	
As per vibration profile B	Components installed on the transmission	
As per Vibration profile C	Components installed at the decoupled intake plenum	
As per vibration profile D	Components installed on sprung masses (body)	
As per vibration profile E	Components installed on unsprung masses (wheel, suspension)	
M-05 Mechanical shock	All components	None
M-06 Mechanical shock durability testing	Components installed in or on doors, hoods, and tailgates/trunk lids	Number of shocks
M-07 Coolant circuit pressure pulsation test	Components connected to a coolant circuit	Test medium
M-08 Protection against foreign bodies - IP0x to IP4x, A, B, C, D		IP degree of protection
IP0x	Components that do not require contact protection	
IP1x	Components that require contact protection, or protection against foreign bodies with a diameter of ≥ 50 mm	
IP2x	Components that require contact protection, or protection against foreign bodies with a diameter of $\geq 12,5$ mm	
IP3x	Components that require contact protection, or protection against foreign bodies with a diameter of $\geq 2,5$ mm	
IP4x	Components that require contact protection, or protection against foreign bodies with a diameter of $\geq 1,0$ mm	
Additional letter A	Components that require an additional contact protection with a diameter of ≥ 50 mm	
Additional letter B	Components that require an additional contact protection with a diameter of $\geq 12,5$ mm	
Additional letter C	Components that require an additional contact protection with a diameter of $\geq 2,5$ mm	
Additional letter D	Components that require an additional contact protection with a diameter of $\geq 1,0$ mm	
M-09 Leak test	Components with tightness requirements	Leakage limit (if needed)
K-01 High/low-temperature aging	All components	None
K-02 Incremental temperature test	All components	None
K-03 Low-temperature operation	All components	None

Table 12 (continued)

Test	Must be applied to	Required specifications
K-04 Repainting temperature	Components installed on the vehicle exterior which could be subjected to increased temperatures during repainting	None
K-05 Thermal shock (component)	All components	Test method (Na or Nc), if Nc: test medium
As per DIN EN 60068-2-14 Na (air to air)	Components that are not permanently operated in a fluid	
As per DIN EN 60068-2-14 Nc (medium to medium)	Components that are permanently operated in a fluid (IP X8)	
K-06 Salt spray test with operation, vehicle exterior	Components installed on the vehicle exterior, underbody, or in the engine compartment	None
K-07 Salt spray test with operation, vehicle interior	Components installed at exposed points in the vehicle interior (e.g., side pockets in the luggage compartment, door wet area or spare wheel well)	None
K-08 Damp heat, cyclic	All components	None
K-09 Damp heat, cyclic (with frost)	All components	None
K-10 Water protection – IPX0 to IPX6K	All components	IP degree of protection
Degree of protection IPX0	Components that do not require water protection	
Degree of protection IPX1	Components on which drops falling vertically may not have any adverse effects	
Degree of protection IPX2	Components with an inclination of up to 15° in the installation position on which drops falling vertically may not have any adverse effects	
Degree of protection IPX3	Components on which spray water may not have any adverse effects	
Degree of protection IPX4K	Components on which high-pressure splash water may not have any adverse effects	
Degree of protection IPX5	Components on which water jets may not have any adverse effects	
Degree of protection IPX6K	Components on which strong water jets with high pressure may not have any adverse effects	
K-11 High-pressure cleaning/steam-jet cleaning	Components that may be directly exposed to high-pressure cleaning/steam-jet cleaning or an underbody washing	None
K-12 Thermal shock with splash water	Components installed on the vehicle exterior or in the engine compartment which are expected to be exposed to splash water (e.g., when driving through puddles)	None
K-13 Thermal shock – immersion	Components installed below the fording depth for which temporary immersion in (salt) water is to be expected (e.g., when driving through water) (IPX7)	None
K-14 Damp heat, steady state	All components	Severity

Table 12 (continued)

Test	Must be applied to	Required specifications
K-15 Condensation test with assemblies	Components without a watertight housing	None
K-16 Thermal shock (without housing)	Assemblies of all components	None
K-17 Solar radiation	Components exposed to direct solar radiation in the installation position.	Test profile
K-18 Harmful gas test	Components with open pin contacts and switching contacts	None
K-19 Climate test for components with watertight housings	Components with a watertight housing	None
C-01 Chemical tests	All components	Chemicals, operating mode
L-01 Service life test - mechanical/hydraulic durability testing	Components with mechanical/hydraulic actuation/function cycles such as brake actuations, seat adjustment cycles, and switch/button actuations	Number of function/actuation cycles
L-02 Service life test - high-temperature durability testing	All components	None
L-03 Service life test - temperature cycle durability testing	All components	None

5.3 Test sequence plan

The tests must be carried out as per appendix A.

5.4 Electrical requirements and tests

5.4.1 General

The requirements, test conditions and tests refer to the 12-V vehicle electrical system. Unless otherwise noted, the tests are not electrical service life tests.

5.4.2 Test sequence for electrical tests

The component must be checked in all relevant operating phases as well as partial unit operating phases to ensure that it continues to work in accordance with the specification. The following operating phases must be tested:

- Startup phase/power-up
- Operation with different DUT functions
- Shutdown phase/power-down
- Sleep mode

Each operating phase must be split into partial operating phases. Partial operating phases include, for example:

- Starting up voltage supply systems within the start phase
- Loading the software

- Self-tests within the start phase
- Cyclic self-test phases during operation
- Writing data during the shutdown phase

Notes:

- A time synchronization of the DUT activation system with the test pulse generator is usually required for a specific test during the relevant operating phases and partial operating phases.
- The existing variance in terms of when voltage pulses actually occur can usually only be re-created using highly automated test beds.

Additional operating phases must be agreed upon with the purchaser.

The electrical tests can be performed in any order. The permissible event memory entries and the functional states of the component must be specified for each test.

The test cases in a test must all be performed, provided they have not been determined in the test selection table for electrical tests as per section 5.1.

The electrical tests may be performed during an environmental test (see part II) if this does not contradict the test requirements of the electrical test and the purchaser has approved this approach. If the DUT demonstrates any irregularities during combined tests, the tests must be repeated individually.

Before an electrical test with a defined internal resistance, the test setup must be verified at the DUT connector by means of a reference measurement, and documented. Unless otherwise specified in the test, the reference measurement must be carried out with a dummy load equivalent to 150% of the load current for the operation_{max} operating mode.

The physical analysis as per section 4.14.4 must be carried out on at least one DUT once all electrical tests have been completed.

5.4.3 E-01 Long-term overvoltage

5.4.3.1 Purpose

This test examines component behavior and resistance in the event of long-term overvoltage.

The overvoltage can be caused by a fault of the energy source generating the voltage and recreates a single fault in the power supply.

5.4.3.2 Test

See table 13 and figure 2

Table 13 – Test parameters for E-01 Long-term overvoltage

DUT operating mode	Operation _{max}
V_{\max}	17 V (+4%, 0%)
V_{\min}	13,5 V
t_r	< 10 ms
t_f	< 10 ms
t_1	60 min
T_{test}	$T_{\max} - 20 \text{ K}$
Number of cycles	1
Number of DUTs	At least 6

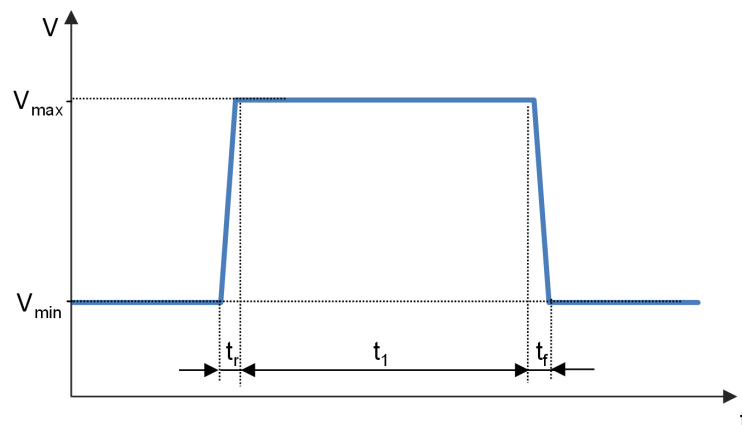


Figure 2 – Test pulse for E-01 Long-term overvoltage

If no thermal steady state (< 1 K in 10 min) has been reached on the DUT after the minimum duration, the test must be prolonged until a thermal steady state is reached.

5.4.3.3 Requirement

See table 1 „Function classes and operating voltage ranges“.

5.4.4 E-02 Transient overvoltage

5.4.4.1 Purpose

Switching off loads and engine revving (tip-in) may result in transient overvoltages in the vehicle electrical system. These overvoltages are simulated in this test.

5.4.4.2 Test

See table 14 and figure 3

**Table 14 – Test parameters for E-02
Transient overvoltage**

DUT operating mode	Driving _{max}
V _{min}	16 V
V ₁	17 V
V _{max}	18 V (+4%, 0%)
t _r	1 ms
t _f	1 ms
t ₁	400 ms
t ₂	600 ms
Number of DUTs	At least 6
Test case 1	
T _{test}	T _{max}
Number of cycles	3
t ₃	2 s
Test case 2	
T _{test}	T _{min}
Number of cycles	3
t ₃	2 s
Test case 3	
T _{test}	T _{RT}
Number of cycles	100
t ₃	8 s

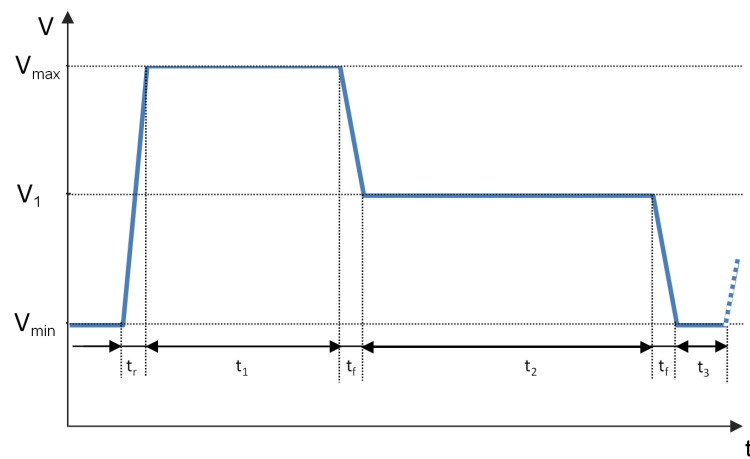


Figure 3 – Test pulse for E-02 Transient overvoltage

5.4.4.3 Requirement

See table 1 „Function classes and operating voltage ranges“.

5.4.5 E-03 Transient undervoltage

5.4.5.1 Purpose

Switching on loads may result in transient undervoltages, depending on the state of the power vehicle electrical system (e.g., availability of energy stores).

5.4.5.2 Test E-03a

See table 15 and figure 4

Table 15 – Test parameters for E-03a
Transient undervoltage

DUT operating mode	Operation _{max}
V _{max}	10,8 V
V _{min}	9 V
t _f	1,8 ms
t ₁	500 ms
t _r	1,8 ms
t ₂	1 s
Number of cycles	10
Test case 1	
T _{test}	T _{max}
Test case 2	
T _{test}	T _{min}

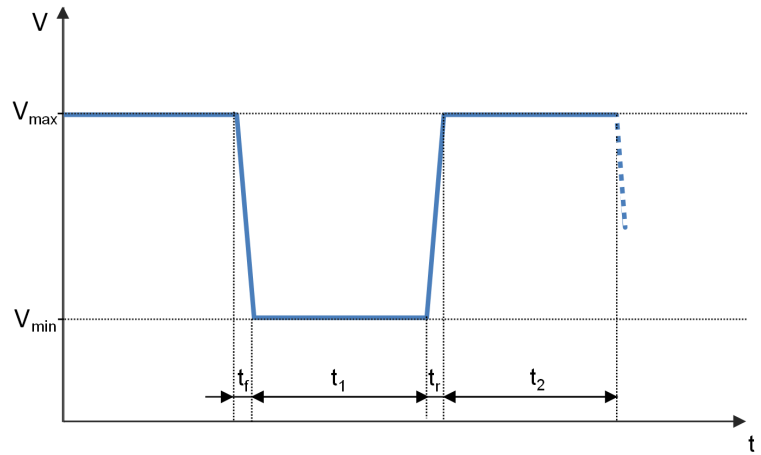


Figure 4 – Test pulse for E-03a Transient undervoltage

5.4.5.3 Test E-03b

See table 16 and figure 5

**Table 16 – Test parameters for E-03b
Transient undervoltage**

DUT operating mode	Operation _{max}
V_1	10,8 V
V_2	6 V
V_3	8 V
V_4	9 V
t_1	5 ms
t_2	20 ms
t_3	2 ms
t_4	180 ms
t_5	1 ms
t_6	300 ms
t_7	2 ms
t_8	1 s
Number of cycles	10
Test case 1	
T_{test}	T_{max}
Test case 2	
T_{test}	T_{min}

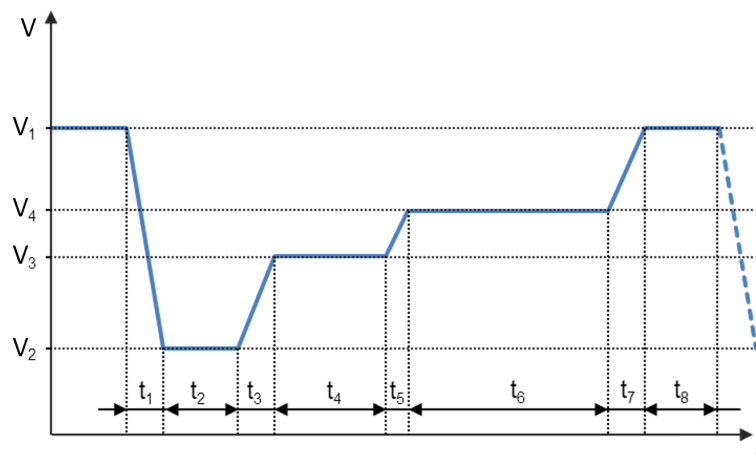


Figure 5 – Test pulse for E-03b Transient undervoltage

5.4.5.4 Requirement

See table 1 „Function classes and operating voltage ranges“.

5.4.6 E-04 Jump start

5.4.6.1 Purpose

This test simulates an external power supply to a vehicle. The maximum test voltage is yielded from commercial vehicle systems and their increased vehicle electrical system voltages.

5.4.6.2 Test

See table 17 and figure 6

Table 17 – Test parameters for E-04 Jump start

DUT operating mode	Operation _{max}
V_0	0 V
V_1	3 V (+0%, -15%)
V_2	10,8 V
V_3	26 V (+4%, 0%)
t_1	1 s
t_2	0,5 s
t_3	5 s
t_4	1 s
t_5	60 s
t_r	< 2 ms
t_f	< 100 ms
Number of cycles	1
Number of DUTs	At least 6

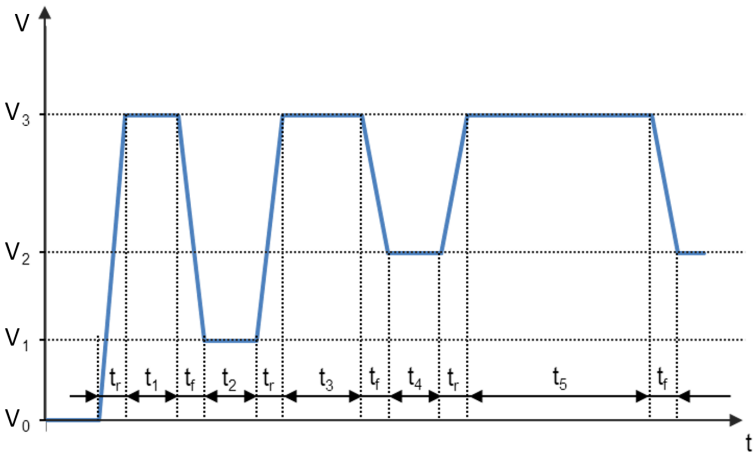


Figure 6 – Test pulse for E-04 Jump start

5.4.6.3 Requirement

See table 1 „Function classes and operating voltage ranges“.

5.4.7 E-05 Load dump

5.4.7.1 Purpose

Dumping of an electric load, in conjunction with a battery with reduced buffering capacity, results in a high-energy overvoltage pulse due to generator properties. This test is meant to simulate this pulse.

5.4.7.2 Test

See table 18 and figure 7

Table 18 – Test parameters for E-05 Load dump

DUT operating mode	Driving _{max}
V_{min}	13,5 V
V_{max}	27 V (+4%, 0%)
R_i	$\leq 100 \text{ m}\Omega$
t_r	$\leq 2 \text{ ms}$
t_1	300 ms
t_f	$\leq 30 \text{ ms}$
Break between cycles	1 min
Number of cycles	10
Number of DUTs	At least 6

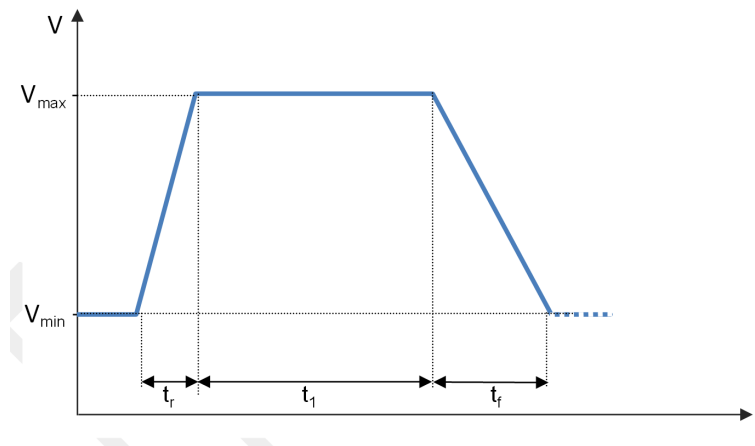


Figure 7 – Test pulse for E-05 Load dump

5.4.7.3 Requirement

See table 1 „Function classes and operating voltage ranges“.

5.4.8 E-06 Ripple voltage

5.4.8.1 Purpose

Alternating (AC) voltages may be superimposed on the vehicle electrical system. The ripple voltage may be present throughout operation. These tests simulate this situation.

5.4.8.2 Test

See table 19 and figure 8

Table 19 – Test parameters for E-06 Ripple voltage

DUT operating mode	Driving _{max}
V _{max}	V _{opmax}
R _i	≤ 100 mΩ
Type of wobble	Triangle, logarithmic
Number of cycles	15
Number of DUTs	At least 6
Test case 1	
V _{PP}	2 V (+4%, 0%)
Frequency range	15 Hz - 30 kHz
Wobble period t ₁	2 min
Test case 2	
V _{PP}	3 V (+4%, 0%)
Frequency range	15 Hz - 30 kHz
Wobble period t ₁	2 min
Test case 3	
V _{PP}	6 V (+4%, 0%)
Frequency range	15 Hz - 30 kHz
Wobble period t ₁	2 min
Test case 4	
V _{PP}	1 V (+4%, 0%) for components supplied from the DC/DC converter
Frequency range	30 kHz – 200 kHz
Wobble period t ₁	10 min

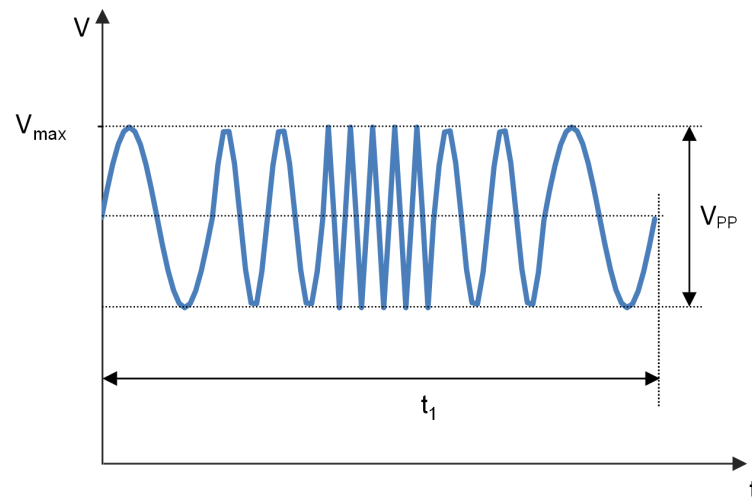


Figure 8 – Test pulse for E-06 Ripple voltage

Test setup

The vehicle electrical system conditions must be agreed upon with the purchaser. The test setup must be documented in detail, including cable inductance values, cable capacitance values, and cable resistance values. The voltage curve (amplitude of DC component and ripple) must be measured on the **DUT** connections, and documented.

5.4.8.3 Requirement

Test case 1:	Functional state A	
Test case 2:	Functional state A	
Tast case 3:	Function class 2:	Functional state A
	Other function classes:	Functional state C
Test case 4:	Functional state A	

5.4.9 E-07 Slow decrease and increase of the supply voltage

5.4.9.1 Purpose

The slow decrease and increase the supply voltage is simulated in the same way as it occurs during slow vehicle battery discharging and charging processes.

5.4.9.2 Test

See table 20 and figure 9

Table 20 – Test parameters for E-07 Slow decrease and increase of the supply voltage

DUT operating mode	Operation _{min} and operation _{max} must be carried out with all relevant states of the voltage supply terminals (e.g., t.15, t.30, t.87) and their combinations
Start voltage	V _{opmax} (+4%, 0%)
Rate of voltage change	0,5 V/min (+10%, -10%)
V ₁	V _{opmin}
t ₁	Hold time at V ₁ until event memory has been read out in full
Minimum voltage	0 V
V ₂	V _{opmin}
t ₂	Hold time at V ₂ until event memory has been read out in full
End voltage	V _{opmax} (+4%, 0%)
Number of cycles	Depending on the relevant terminal status and terminal combinations: 1 cycle in operation _{min} operating mode 1 cycle in operation _{max} operating mode
Number of DUTs	3

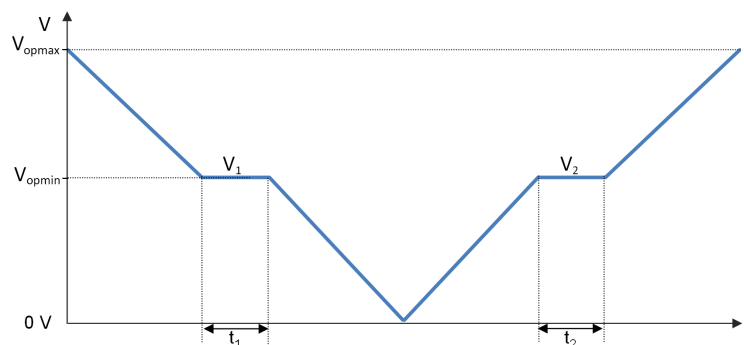


Figure 9 – Test pulse for E-07 Slow decrease and increase of the supply voltage

5.4.9.3 Requirement

Functional states in the static operating voltage range as per table 1 „Function classes and operating voltage ranges“

5.4.10 E-08 Slow decrease, quick increase of the supply voltage

5.4.10.1 Purpose

This test simulates the slow decrease of the battery voltage to 0 V and the sudden re-application of the battery voltage, e.g., from a jump start source.

5.4.10.2 Test

See table 21 and figure 10

Table 21 – Test pulse for E-08 Slow decrease and rapid increase of the supply voltage

DUT operating mode	Operation _{min} and operation _{max} must be carried out with all relevant states of the voltage supply terminals (e.g., t.15, t.30, t.87) and their combinations
Start voltage	V _{opmax} (+4%, 0%)
Voltage drop	0,5 V/min (+10%, -10%)
V ₁	V _{opmin}
t ₁	Hold time at V ₁ until event memory has been read out in full
Minimum voltage	0 V
t ₂	At least 1 min, but as long as is needed until the internal capacities have been fully discharged
End voltage	V _{opmax} (+4%, 0%)
t _r	≤ 0,5 s
Number of cycles	Depending on the relevant terminal status and terminal combinations: 1 cycle in operation _{min} operating mode 1 cycle in operation _{max} operating mode
Number of DUTs	At least 6

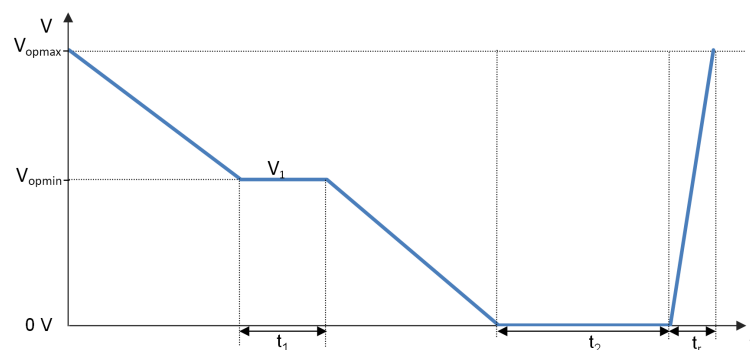


Figure 10 – Test pulse for E-08 Slow decrease and rapid increase of the supply voltage

5.4.10.3 Requirement

Functional states in the static operating voltage range as per table 1 „Function classes and operating voltage ranges“

5.4.11 E-09 Reset behavior

5.4.11.1 Purpose

The reset behavior of a component in its environment is recreated and tested. Test conditions (e.g., ECU network, terminal, system) must be described in detail.

An arbitrary chronological sequence of repeated switch-on/switch-off processes occurs during operation and may not result in undefined component behavior. The reset behavior is reflected in a voltage variance and in a time-based variance. Two different test sequences are required to simulate varying switch-off times. A component must always run through the two sequences.

5.4.11.2 Test

See table 22 and figure 11

Table 22 – Test parameters for E-09 Reset behavior

DUT operating mode	Operation _{min} , driving _{min} and operation _{max} must be carried out with all relevant statuses of the voltage supply terminals (e.g., t.15, t.30, t.87) and their combinations
V _{max}	V _{opmin} (0%, -4%)
V _{th}	6 V
ΔV ₁ (range V _{max} to V _{th})	0,5 V
ΔV ₂ (range V _{th} to 0 V)	0,2 V
t ₂	At least 10 s and until the DUT has reached 100% operability again (all systems rebooted without errors)
t _r	≤ 10 ms
t _f	≤ 10 ms
Number of cycles	For each test sequence per relevant terminal status and status combinations: 1 cycle with operation _{min} operating mode 1 cycle with driving _{min} operating mode 1 cycle with operation _{max} operating mode
Number of DUTs	At least 3
Test case 1	
t ₁	5 s
Test case 2	
t ₁	100 ms

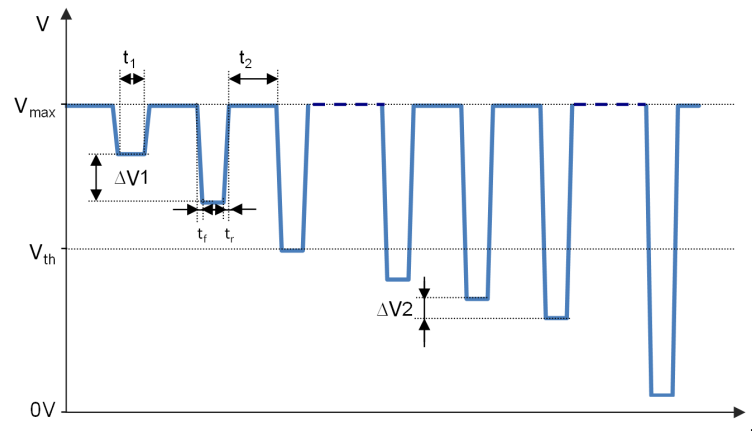


Figure 11 – Test pulse for E-09 Reset behavior

5.4.11.3 Requirement

Functional state A once V_{\max} is reached again

Undefined functions are not permissible at any time.

Proof of adherence to the specified threshold value must be provided. The voltage level starting from which the component leaves functional state A for the first time must be recorded.

5.4.12 E-10 Brief interruptions

5.4.12.1 Purpose

This test simulates the behavior of the **component** in the event of brief interruptions of varying durations.

Test case 1 represents a supply voltage interruption at the **component**.

Test case 2 represents a supply voltage interruption in the vehicle electrical system.

Such interruptions can occur due to events such as contact faults and line faults or relay-contact bounce.

5.4.12.2 Test

See **table 23** and **figure 12**

Table 23 – Test parameters for E-10 Brief interruptions

DUT operating mode	Operation _{max}	
V _{test}	11 V	
State 1 (Z1)	Switch 1 (S1) closed	
Z2	S1 open	
t _r	≤ (0,1 × increment)	
t _f	≤ (0,1 × increment)	
Switch S1 must be switched with the following sequences:	t _i	Increment
	10 μs to 100 μs	10 μs
	100 μs to 1 ms	100 μs
	1 ms to 200 ms	1 ms
	200 ms to 2 s	100 ms
t ₂	> 10 s The test voltage V _{test} must be held at least until the DUT and the periphery have reached 100% operability again.	
Number of cycles	1	
Number of DUTs	At least 6	
Test case 1	S1 switched, S2 statically open	
Test case 2	S1 switched, S2 inverted relative to S1	

The duration of the voltage sag is increased by the increment specified in **table 23**. This yields the diagram shown in **figure 12**.

The voltage on the **DUT** can be limited by the test setup to the maximum voltage of test E-05 Load dump (see section 5.4.7).

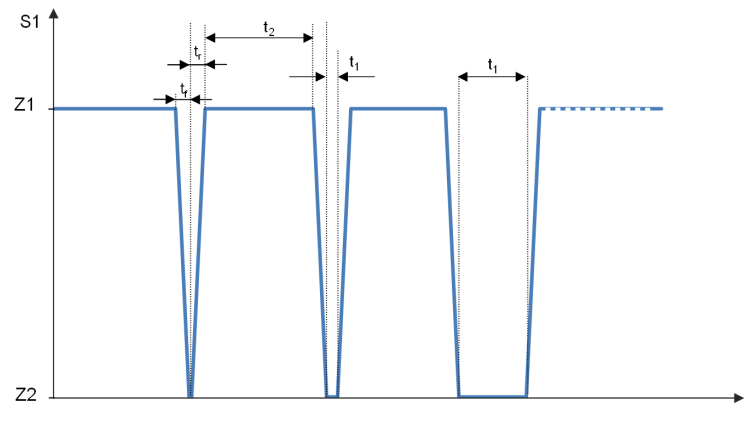


Figure 12 – Change in state of switch S1 for E-10 Brief interruptions

5.4.12.2.1 Test setup

See figure 13.

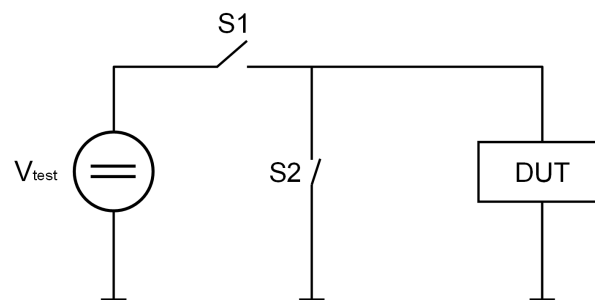


Figure 13 – Schematic circuit diagram for E-10 Brief interruptions

The closed switch S2, including the necessary cables, must be implemented with a series resistance of $< 100 \text{ m}\Omega$.

5.4.12.2.2 Test sequence

One reference measurement each with $100 \text{ }\Omega$ ($\pm 5\%$) and $1 \text{ }\Omega$ ($\pm 5\%$) as a DUT dummy must be carried out and documented. The slew rate must be verified with this test setup. Low-inductance components must be used as resistors.

Then the tests must be carried out as per table 23.

5.4.12.3 Requirement

See table 1 „Function classes and operating voltage ranges“.

The time value t_1 beyond which the DUT leaves functional state A for the first time must be recorded.

5.4.13 E-11 Start pulses

5.4.13.1 Purpose

When starting (starting up the engine), the battery voltage drops to a low value for a short period of time and then increases slightly again. Most functions are briefly activated immediately before the starting process, deactivated during the starting process, and then activated again after the starting process once the engine is running. This test examines the behavior of the functions in the event of voltage sags caused by starting.

The starting process may be carried out under varying vehicle starting conditions: cold start and hot start (automatic restart in the case of a start-stop system). In order to cover both cases, two different test cases are required. A function must always run through the two sequences.

5.4.13.2 Test

See table 24.

Table 24 – Test parameters for E-11 Start pulses

DUT operating mode	Operation _{min} , driving _{min} and operation _{max} Other operating loads may need to be determined in the respective operating mode.
Test pulse	<ul style="list-style-type: none"> – Cold start: „normal“ and „severe“ test pulse as per table 25 – Hot start: „short“ and „long“ test sequence as per table 26
Number of DUTs	At least 6

5.4.13.2.1 Test case 1 - Cold start

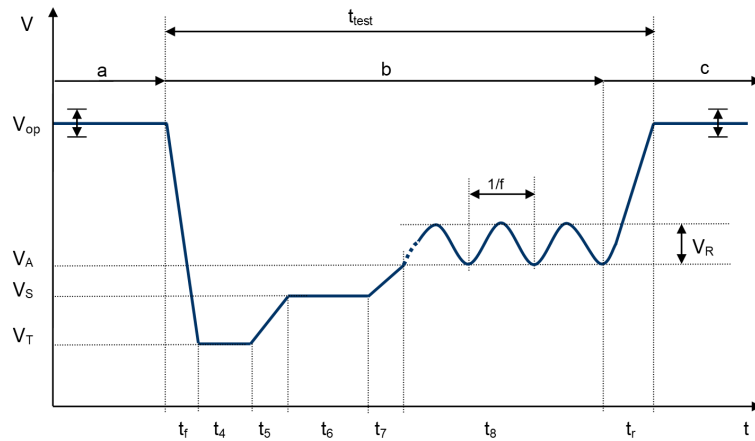
See table 25 and figure 14

Table 25 – Test parameters for E-11 Cold start

Parameter	„Normal“ test pulse	„Severe“ test pulse
V _{op}	11,0 V	11,0 V
V _T	4,5 V (0%, -4%)	3,2 V (+0,2 V, 0 V)
V _S	4,5 V (0%, -4%)	5,0 V (0%, -4%)
V _A	6,5 V (0%, -4%)	6,0 V (0%, -4%)
V _R	2 V	2 V
t _i	≤ 1 ms	≤ 1 ms
t ₄	0 ms	19 ms
t ₅	0 ms	≤ 1 ms
t ₆	19 ms	329 ms
t ₇	50 ms	50 ms
t ₈	10 s	10 s
t _r	100 ms	100 ms
f	2 Hz	2 Hz

Table 25 (continued)

Parameter	„Normal“ test pulse	„Severe“ test pulse
Break between cycles	2 s	2 s
Number of cycles	10	10



Legend

a	t.50 off
b	t.50 on
c	t.50 off
t _{test}	Cycle

Figure 14 – Test pulse for E-11 Cold start

5.4.13.2.2 Test case 2 - Hot start:

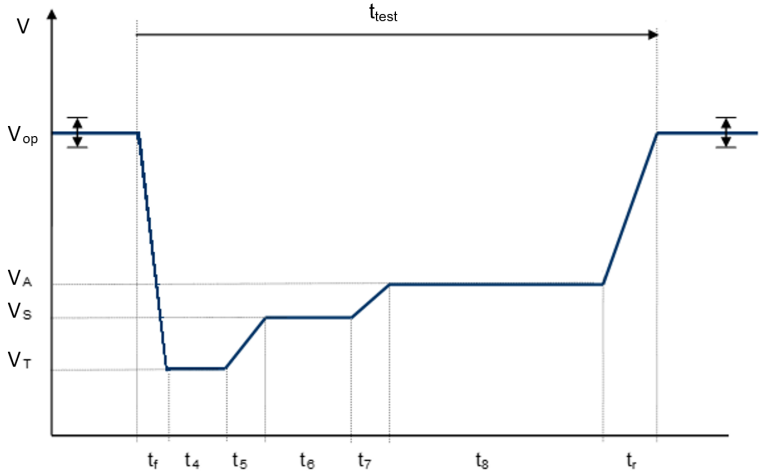
See [table 26](#) and [figure 15](#)

Table 26 – Test parameters for E-11 Hot start

Parameter	„Short“ test sequence:	„Long“ test sequence:
V _{op}	11,0 V	
V _T	7,0 V (0%, -4%)	
V _S	8,0 V (0%, -4%)	
V _A	9,0 V (0%, -4%)	
t _f	≤ 1 ms	
t ₄	15 ms	
t ₅	70 ms	
t ₆	240 ms	
t ₇	70 ms	
t ₈	600 ms	
t _r	≤ 1 ms	

Table 26 (continued)

Parameter	„Short“ test sequence:	„Long“ test sequence:
Break between cycles	5 s	20 s
Number of cycles	10	100



Legend

t_{test} Cycle

Figure 15 – Test pulse for E-11 Hot start

5.4.13.3 Requirement

5.4.13.3.1 Functions that are relevant for a cold start

Test case 1 - Cold start:

„Normal“ test pulse: Functional state A

„Severe“ test pulse: Functional state A

Test case 2 - Hot start:

„Long“ test sequence: Functional state A

„Short“ test sequence: Functional state A

5.4.13.3.2 Functions that are not relevant for a cold start

Test case 1 - Cold start:

„Normal“ test pulse: Functional state C

„Severe“ test pulse: Functional state C

Test case 2 - Hot start:

„Long“ test sequence: Functional state A

„Short“ test sequence: Functional state A

5.4.14 E-12 Voltage curve with vehicle electrical system control

5.4.14.1 Purpose

This test simulates the behavior of the vehicle electrical system with voltage controls, e.g., with the use of intelligent generator or DC/DC converter controls. Voltage curves in the range between constant voltage up to permanent voltage fluctuations can be set by the control system in accordance with test cases as per table 27. This is relevant to all load cases that the component can assume with the „engine running“ or the „vehicle ready for operation“.

5.4.14.2 Test

See table 27 and figure 16

Table 27 – Test parameters for E-12 Voltage curve with vehicle electrical system control

DUT operating mode	Driving _{max}
V_{\min}	(11,8 V - ΔV) (0%, -4%)
V_{\max}	(16 V - ΔV) (+4%, 0%)
t_1	2 s
t_r	400 ms
t_f	400 ms
Number of cycles	10
Number of DUTs	At least 6
Test case 1	
ΔV	0 V
Test case 2	
ΔV	0,7 V
Test case 3	
ΔV	2 V

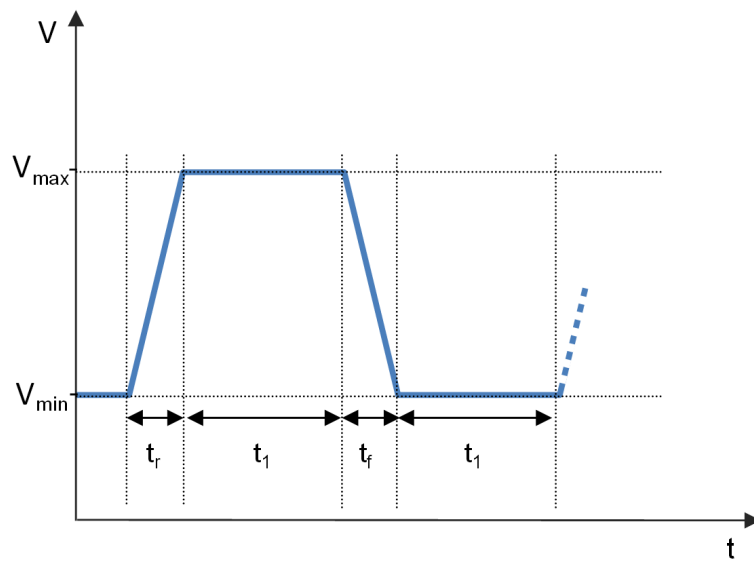


Figure 16 – Test pulse for E-12 Voltage curve with vehicle electrical system control

5.4.14.3 Requirement

Functional state A

5.4.15 E-13 Pin interruption

5.4.15.1 Purpose

This test simulates the line interruption of individual pins. Different pulse forms must be used, because the possible interruptions may differ greatly in terms of their duration (from loose contacts to permanent interruption).

5.4.15.2 Test

See table 28 and figure 17

Table 28 – Test parameters for E-13 Pin interruption

DUT operating mode	Operation _{min} and operation _{max} must be carried out with all relevant states of the voltage supply terminals (e.g., t.15, t.30, t.87) and their combinations
Z1	State 1: pin connected
Z2	State 2: pin interrupted
t_r	$\leq (0,1 \times t_1)$
t_f	$\leq (0,1 \times t_1)$
Number of cycles	The following applies to the two test cases and the relevant terminal statuses: 3 cycles with operation _{min} operating mode 3 cycles with operation _{max} operating mode Each test must be evaluated separately.
Number of DUTs	At least 6
Test case 1	Each pin must be removed for $t = 10$ s and then replaced (slow interval).
Test case 2	Burst on each pin in order to simulate a „loose contact“
Number of pulses t_2 in the burst	4 000
a	Burst
t_1	0,1 ms
t_2	1 ms
t_3	10 s

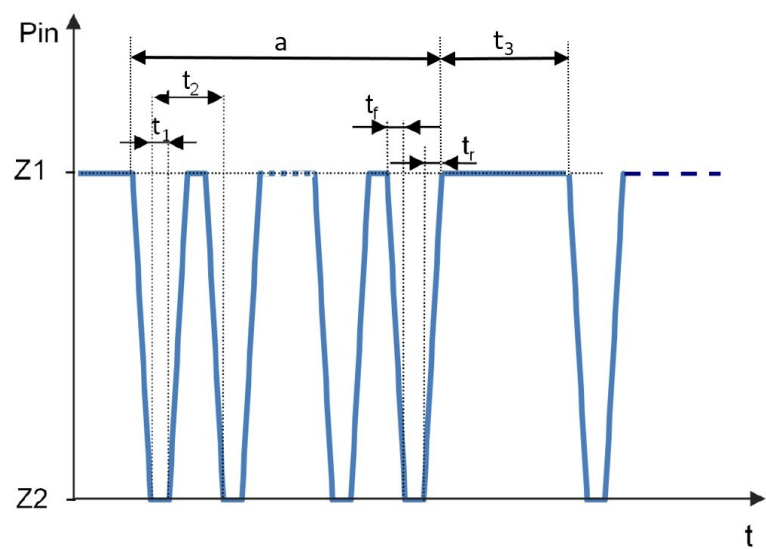


Figure 17 – Test pulse for E-13 Pin interruption, test case 2

Test sequence

The component is connected to the voltage supply. The test must not be carried out on the supply pins (e.g., t.15, t.30, t.87), unless one of these pins is used as a wake-up line. The test must also be performed on ground pins (t.31).

One reference measurement each with 1 kΩ (±5%) and 1 Ω (±5%) as a DUT dummy must be carried out and documented. The slew rate must be verified with this test setup. Low-inductance components must be used as resistors.

Then the tests must be carried out as per table 28.

5.4.15.3 Requirement

For all test cases: functional state C

5.4.16 E-14 Connector interruption

5.4.16.1 Purpose

This test simulates the line interruption of connectors.

5.4.16.2 Test

See table 29.

**Table 29 – Test parameters for E-14
Connector interruption**

DUT operating mode	Operation _{min} and operation _{max}
Number of cycles	Each connector must be removed once in both operating modes.
Number of DUTs	At least 6

Test sequence

Each connector must be removed from the DUT for 10 s and then replaced. If the DUT has several connectors, each connector must be tested individually. The test sequence must be varied. If there are several connectors, their combinations must also be tested.

5.4.16.3 Requirement

Functional state C

5.4.17 E-15 Reverse polarity

5.4.17.1 Purpose

A test is carried out to verify the resistance of the DUT to a reverse polarity connection of a battery when assisting with a jump start. Reverse polarity can occur several times and must not cause damage to the component. Reverse polarity protection must be ensured for any voltages down to the minimum test voltage. The vehicle fuse is not part of the reverse polarity protection strategy.

5.4.17.2 Test

All relevant connections of the original circuitry must be tested. The DUT must be activated according to the circuitry in the vehicle. The test must be performed at various voltages between 0 V and the maximum values specified in table 30.

The current draw during the test must be documented.

Table 30 – Test parameters for E-15 Reverse polarity

DUT operating mode	Operation _{min} (static reverse polarity) Operation _{max} (dynamic reverse polarity)
Test case 1	Static reverse polarity as per table 31
Test case 2	Dynamic reverse polarity as per table 32
Number of DUTs	At least 6

5.4.17.2.1 Test case 1 - Static reverse polarity

This test case tests the robustness of the component at various reverse polarity voltages that can arise depending on the vehicle state.

See table 31 and figure 18

Table 31 – Test parameters for E-15 Static reverse polarity

V_{\max}	0 V
V_{\min}	-14,0 V
ΔV_1	-1 V
Severity 1	$R_i < 100 \text{ m}\Omega$
Severity 2	$R_i < 30 \text{ m}\Omega$
t_1	60 s For a component for which the operating voltage is switched off by a relay in the event of reverse polarity, the following deviating value applies: 8 ms.
t_2	$\geq 60 \text{ s}$, but at least until the component has reached the same thermal state as at the start of the test
t_r	$\leq 10 \text{ ms}$
t_f	$\leq 10 \text{ ms}$
Number of cycles	1

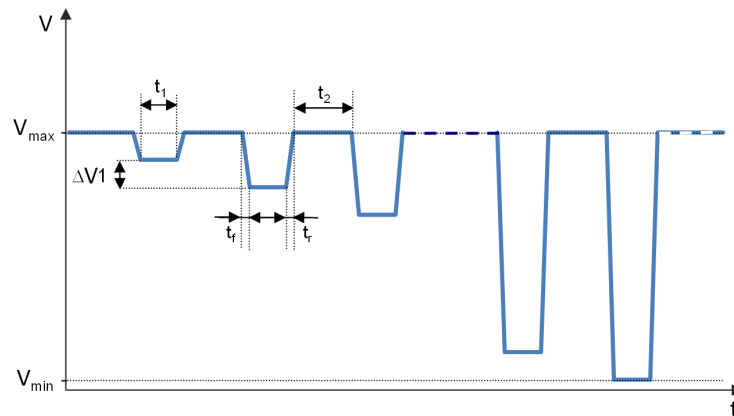


Figure 18 – Test pulse for E-15 Static reverse polarity

5.4.17.2.2 Test case 2 - Static reverse polarity

This test case checks the resistance of the component against reverse polarity during operation in a vehicle that is no longer capable of starting.

See table 32 and figure 19

Table 32 – Test parameters for E-15 Dynamic reverse polarity

V_{\max}	10,8 V
V_{\min}	-4,0 V
Severity 1	$R_i < 100 \text{ m}\Omega$
Severity 2	$R_i < 30 \text{ m}\Omega$
t_1	60 s For a component for which the operating voltage is switched off by a relay in the event of reverse polarity, the following deviating value applies: 8 ms.
t_2	$\leq 5 \text{ min}$
t_r	$\leq 10 \text{ ms}$
t_f	$\leq 10 \text{ ms}$
Number of cycles	3

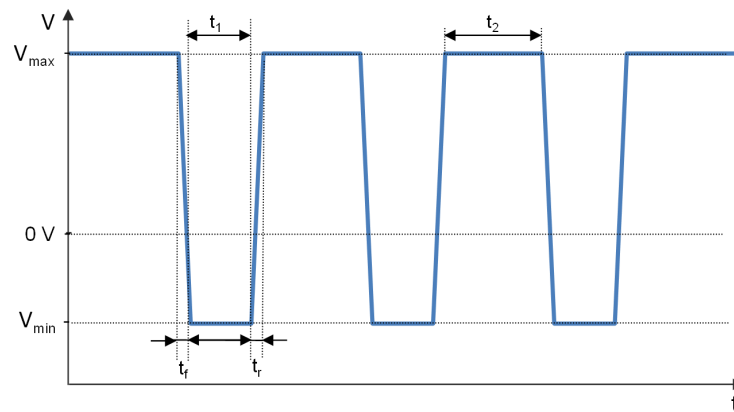


Figure 19 – Test pulse for E-15 Dynamic reverse polarity

5.4.17.3 Requirement

Safety-relevant functions, e.g., of power windows, the power sliding sunroof, or the starter, must not be triggered during periods of reverse polarity.

Functional state C

5.4.18 E-16 Ground potential difference

5.4.18.1 Purpose

Differences in potential between various ground connection points may cause signal falsifications between components at these connection points. It must be ensured that potential differences between ground points up to a magnitude of ± 1 V (static) in the vehicle electrical system including the ECU network do not affect component functions.

5.4.18.2 Test

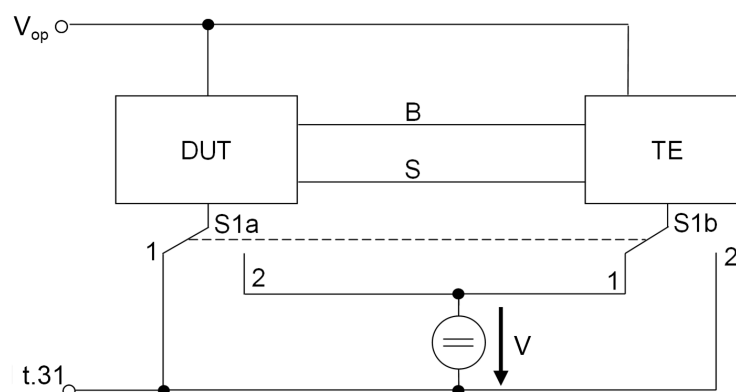
If the DUT has several voltage and ground connections, the test must be carried out separately for each connection point.

The component is connected as shown in figure 20.

See table 33 and figure 20

Table 33 – Test parameters for E-16 Ground potential difference

DUT operating mode	Operation _{max}
Test duration	≥ 60 s
V	1 V
Number of cycles	Both switching positions
Number of DUTs	At least 6



Legend

- B Bus system
- S Signal cable
- S1 Two-pin (a/b) change-over switch
- TE Another component, e.g., test reference, test bed, simulation control module, actuator, sensor, or load

Figure 20 – Schematic circuit diagram for E-16 Ground potential difference

5.4.18.3 Requirement

Functional state A

5.4.19 E-17 Short circuit in signal cable and load circuits

5.4.19.1 Purpose

This test simulates short circuits on all device inputs and outputs and in the load circuit.

All inputs and outputs must be short-circuit-proof to t.30 and t.31 (for activated and non-activated outputs, with and without voltage supply, and with and without ground connection).

The component must be designed to withstand a sustained short circuit.

5.4.19.2 Test

See table 34.

Table 34 – Test parameters for E-17 Short circuit in signal cable and load circuits

DUT operating mode	Test case 1: operation _{max} Test case 2 - 4: I.c
Test duration	Each combination of test voltage and test case for 60 s
Test voltages	V _{opmin} and V _{opmax}
Test case 1	Each pin except for GND pins, alternately to t.30 and t.31 with voltage supply and with ground connection
Test case 2	Each pin except for GND pins, alternately to t.30 and t.31 without voltage supply and with ground connection
Test case 3	Each pin alternately to t.30 and t.31 with voltage supply and without ground connection
Test case 4	Each GND pin against t.30 with voltage supply and with ground connection
Number of DUTs	At least 6 The test must be carried out with one DUT only for individual test steps that lead to functional state E.

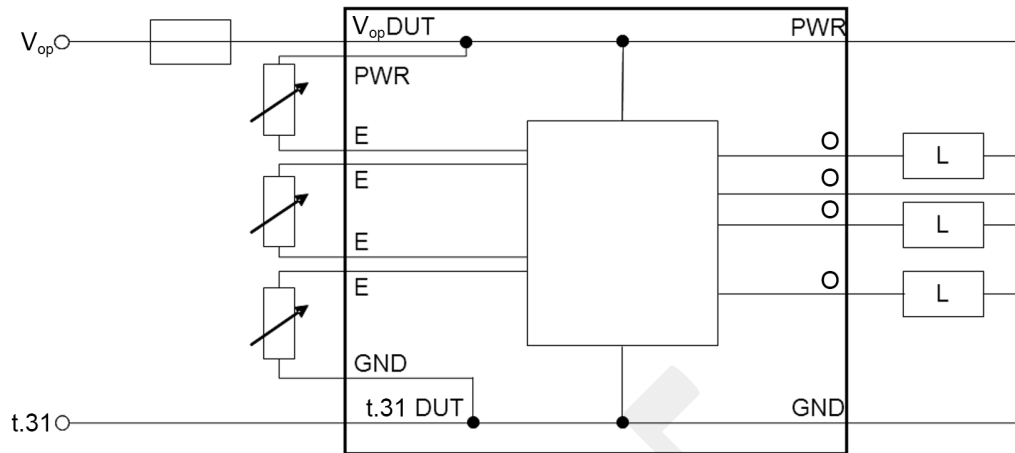
If the voltage supply/ground supply is fed via several pins, these combinations must also be taken into account.

Test case 4 is used to test multiple faults that may occur, e.g., in the bending areas of wiring harnesses in doors and tailgates/trunk lids. The voltage supply line with the highest current-carrying capacity running parallel in the bending area must be used to design the test setup.

5.4.19.2.1 Test setup

For tests in which the short-circuit current flows to the component via a supply cable, the test setup in terms of the short-circuit current and fusing must at least be able to recreate the situation in the vehicle, and the power supply unit used must be able to deliver the short-circuit currents to which the component can be expected to be exposed. If this is not possible, the power supply unit may be buffered using a car battery (V_{opmax} is the maximum charging voltage in this case).

See figure 21.



Legend

V_{op}	Voltage supply
T. 31	Ground connection
L	Load
I	Input
O	Output
PWR	Output V_{op} DUT
GND	Ground input/output (without t. 31 DUT)

Figure 21 – Schematic circuit diagram for E-17 Short circuit in signal cable and load circuits

5.4.19.2.2 Test sequence

For inputs/outputs: Record and evaluate the short-circuit current over time

The functional effects of the short circuits must be documented.

5.4.19.3 Requirement

Functional state C: For inputs and outputs (I and O)

Functional state D2: For looped-through supply voltages (PWR)

Functional state E: For device ground (GND)

5.4.20 E-18 Insulation resistance

5.4.20.1 Purpose

The insulation resistance of 12-V circuits is tested.

The test must be applied to:

- Insulation that is relevant to quiescent current (if available, e.g., after any moisture treatment)
- Motor windings
- Relay, between the contacts or the winding and the contacts

5.4.20.2 Test

See table 35.

Table 35 – Test parameters for E-18 Insulation resistance

DUT operating mode	I.a
Test voltage	500 V DC
Test duration	60 s
Test points	The test points must be selected depending on the component setup and internal wiring, and they must be agreed upon with the purchaser prior to the start of the test.
Number of cycles	1
Number of DUTs	At least 6

Test sequence

This test must be carried out after the „Damp heat, constant“ and „Damp heat, cyclic“ tests.

After the „Damp heat, constant“ test, the DUTs must be ventilated for 30 min before the insulation resistance is measured.

The insulation resistance must be measured immediately after the „Damp heat, cyclic“ test.

5.4.20.3 Requirement

The insulation resistance must be at least 10 MΩ.

Functional state A must be verified after the test.

5.4.21 E-19 Quiescent current

5.4.21.1 Purpose

The quiescent-current draw of the component is to be determined at variable temperatures.

5.4.21.2 Test

In the case of components that have a post-run function (e.g., fan), the quiescent-current draw may only be determined once this function has been terminated. In the case of components that have a cyclic wake-up function built in (e.g., charge control system), this function must be taken into account (e.g., duration and sampling rate).

The component must be measured with the associated peripherals and circuitry.

See table 36.

**Table 36 – Test parameters for E-19
Quiescent current**

DUT operating mode	Idle state/parking _{min}
Test voltage	12,5 V (+4%, 0%)
Number of cycles	1
Number of DUTs	At least 6

Test sequence

The quiescent current must be continuously monitored during the test.

The current curve with a superimposed temperature curve must be documented using graphs.

Minimum, maximum, and average quiescent-current values must be determined and documented.

See table 37 and figure 22

**Table 37 – Test parameters for E-19
Quiescent current**

t ₁	60 min
t ₂	90 min
t ₃	240 min
t ₄	270 min
t ₅	360 min

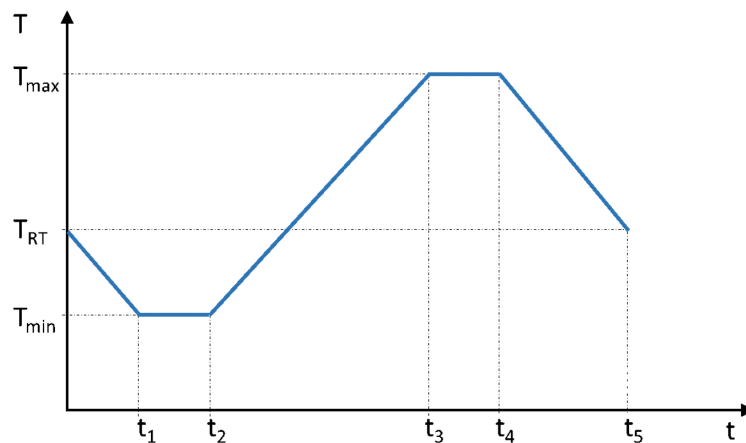


Figure 22 – Test sequence for E-19 Quiescent current

5.4.21.3 Requirement

The following applies during the sleep phase:

Temperature $\leq 40\text{ }^{\circ}\text{C}$: Temporal mean of quiescent current $\leq 100\text{ }\mu\text{A}$

Temperature $> 40\text{ }^{\circ}\text{C}$: Temporal mean of quiescent current $\leq 200\text{ }\mu\text{A}$

For DUTs that must be operated after t.15 off, a quiescent-current draw equivalent (averaged over 12 h) $\leq 100\text{ }\mu\text{A}$, corresponding to 1,2 mAh applies in the idle phase.

5.4.22 E-20 Dielectric strength

5.4.22.1 Purpose

The dielectric strength of 12-V circuits is tested.

The test must be applied to:

- Insulation that is relevant to quiescent current (if available, e.g., after any moisture treatment)
- Motor windings
- Relay, between the contacts or the winding and the contacts

5.4.22.2 Test

See table 38.

Table 38 – Test parameters for E-20 Dielectric strength

DUT operating mode	I.a
Test voltage V_{RMS}	500 V AC, 50 Hz, sinusoidal
Test duration	60 s
Test points	The test points must be selected depending on the component setup and internal wiring, and they must be agreed upon with the purchaser prior to the start of the test.
Number of cycles	1
Number of DUTs	At least 6

Test sequence

This test must be carried out after the „Damp heat, constant“ and „Damp heat, cyclic“ tests.

After the „Damp heat, constant“ test, the DUTs must be ventilated for 30 min before the test is carried out.

The test must be carried out immediately after the „Damp heat, cyclic“ test.

5.4.22.3 Requirement

Dielectric breakdowns and electric arcs are not permissible.

5.4.23 E-21 Backfeeds

5.4.23.1 Purpose

The independence of switched terminals must be ensured.

This test verifies that the DUT is free of backfeeds to switched terminals (t.15, t.87, t.30c, etc.).

5.4.23.2 Test

See table 39 and figure 23

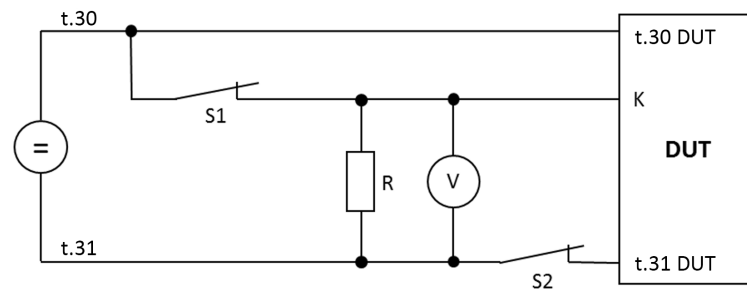
Table 39 – Test parameters for E-21 Backfeeds

DUT operating mode	Operation _{max}
V _{test}	V _{opmax} - 0,2 V
Test temperatures	T _{max} , T _{RT} and T _{min}
Test case 1	
R	Not present
S1	Open
S2	Closed
Test case 2	
R	≥ 10 kΩ
S1	Open
S2	Open
Number of DUTs	At least 6

Test sequence

The DUT must be connected according to the circuitry in the vehicle (including sensors, actuators, etc.) and operated in normal operation. Switches S1 and S2 are closed. The voltage curve at the terminal being tested must be measured during switch-off of the terminal. To do this, the switches must be opened as per table 39. The terminal must be switched off, e.g., by means of a relay or a switch ($R_{\text{switch_open}} \rightarrow \infty$). Other voltage sources that may be available, such as t.30, may not be disconnected or switched off during the test (in accordance with the behavior in the vehicle).

The voltage curve at the terminal being tested must be measured using a measuring device (V) with an input resistance of ≥ 10 MΩ (e.g., oscilloscope).



Legend

S1	Switch 1
S2	Switch 2
R	Resistance
K	Terminal to be tested
V	Measuring instrument

Figure 23 – Schematic circuit diagram for E-21 Backfeeds

5.4.23.3 Requirement

The voltage at the non-wired terminal being tested must drop below a voltage of 1 V within $t = 20$ ms from the time of the switch-off.

The voltage curve over time must continuously fall. Discontinuity of the curve due to positive pulses is not permitted.

5.4.24 E-22 Overcurrents

5.4.24.1 Purpose

This test examines the overcurrent strength of mechanical switches, electronic outputs, and contacts. Higher currents than in the normal load case (e.g., maximum stalling current I_{stall} of a motor) must also be taken into account.

5.4.24.2 Test

See table 40.

Table 40 – Test parameters for E-22 Overcurrents

DUT operating mode	Operation _{max}
Temperature	T_{max}
Test condition for electronic outputs	The output must be able to withstand three times the nominal load without sustaining any damage.
t_{test}	30 min
Test conditions for switched outputs	<p>For components with an $I_N \leq 10 \text{ A}$: $I_{\text{test}} = 3 \times I_N$</p> <p>For components with an $I_N > 10 \text{ A}$: $I_{\text{test}} = 2 \times I_N$, but at least 30 A and max. 150 A</p> <p>For components with an $I_{\text{block}} > 3 \times I_N$: $I_{\text{test}} = I_{\text{block}}$</p> <p>They must be switched „OFF“, „ON“, and „OFF“ again under load.</p> <p>Loading duration: 10 min</p> <p>If there are multi-contact relays/switches, each contact must be tested individually.</p>
Number of DUTs	At least 6

5.4.24.3 Requirement

Functional state A for mechanical components without a fuse. If fuses are present in the load circuit, it is permissible for them to trip.

Functional state C for electronic outputs with overload detection (current, voltage, temperature).

The physical analysis must verify that the DUT has not been damaged.

5.4.25 E-23 Equalizing currents of multiple supply voltages

5.4.25.1 Purpose

The test must be used for components that are connected to additional 12-V electrical systems that are independent of one another, and that each have their own energy store.

This test is used to check that any quiescent currents in individual electrical systems do not influence other networks.

5.4.25.2 Test

See table 41.

Table 41 – Test parameters for E-23 Compensating currents

DUT operating mode	I.c
t_{test}	60 s
Test points	Application of the test voltage between – the two supply connections, see figure 24 – Additional testing points must be agreed upon with the purchaser.
Number of cycles	1
Number of DUTs	6
Test case 1	
V_{test}	32 V
Test case 2	
V_{test}	-32 V

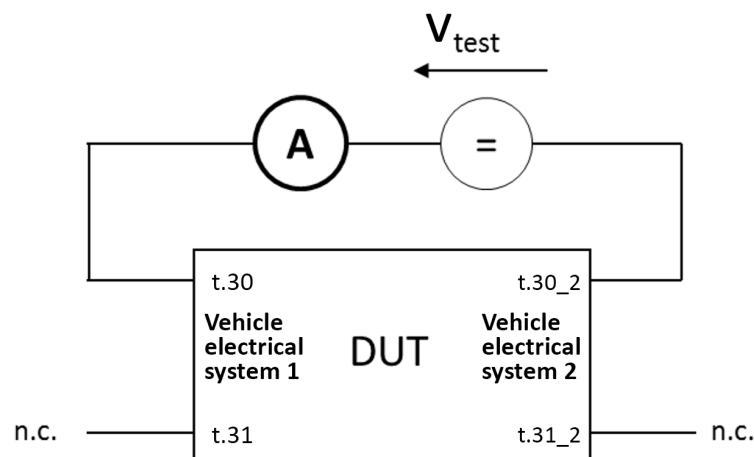


Figure 24 – Schematic circuit diagram for E23 Compensating currents

5.4.25.3 Requirement

The equalizing current measured in the test setup must not exceed 100 μA . Functional state A must be verified after the test.

5.4.26 E-24 ON/OFF durability testing

5.4.26.1 Purpose

The purpose of this test is to verify that the component can initialize, start up and shut down reliably.

5.4.26.2 Test

See table 42.

Table 42 – Test parameters for E-24 ON/OFF durability testing

DUT operating mode	Operation _{min} (sleep), stationary state with an operating load (to be agreed upon with the purchaser)
Test temperatures	T _{min} , T _{RT} , T _{max}
Supply voltages for the 12-V level	V _{opmin} , V _{op} , V _{opmax}
Other supply voltages	48 V, HV _{AC} , HV _{DC} , if available
Number of DUTs	At least 6

5.4.26.2.1 Test E-24a - ON/OFF durability testing

See table 43.

Table 43 – Test parameters for E-24a ON/OFF durability testing

Number of cycles	54 000 in driving operating mode Additionally 46 000, e.g., for charging, preconditioning
Activation	e.g., t.15, t.87, t.15 via network
Distribution of cycles	<div> 70% at T_{RT} 20% at T_{max} 10% at T_{min} </div> <div>At each temperature level:</div> <div> 33% at V_{opmin} 34% at V_{op} 33% at V_{opmax} </div>

All supply inputs that are connected and switched in the vehicle (e.g., t.15, t.87) must be switched on and off in a cycle. If this is controlled using signals or a communication bus (e.g., t.15 via CAN, the signals must be set accordingly.

The order and time sequence of switching the supply voltages on and off as well as of the bus signaling must be recreated in accordance with the conditions in the vehicle.

The component is in an electrically idle state at the beginning of the cycle. After switched supply inputs or signals have been activated, the component starts up fully until it reaches a stationary state with operating load.

The stationary state with operating load must be agreed upon with the purchaser. There may also be multiple stationary states with operating load depending on the operating situations.

After switched supply inputs or signals are deactivated, the component switches off fully until it reaches an electrically idle state (mechatronic rest position, end of post-run, sleep).

A cycle ends when all supply voltages that have been switched or generated in the component have decreased to less than 10% of their nominal values.

5.4.26.2.2 Test E-24b - T.30 cycle

See table 44.

Table 44 – Test parameters for E-24b - T.30 cycle

Number of cycles	100
Activation	T.30, t.30c - if available
Distribution of cycles	<p>70% at T_{RT} 20% at T_{max} 10% at T_{min}</p> <p>At each temperature level:</p> <p>33% at V_{opmin} 34% at V_{op} 33% at V_{opmax}</p>
	30 s Duration while t.30 is present

At the start of a cycle, the component is fully live and the t.30 voltage supply is switched off.

The component must initialize after switching on t.30 and must reach functional state A depending on the signals that are present (e.g., t.15, t.15 via CAN). A cycle ends after t.30 has been switched off and all supply voltages that have been generated inside the component have decreased to less than 10% of their nominal values.

An existing supply via t.30 or other redundant voltage supply systems must be tested in relationship to one another and to t.30 in all combinations specified in the Performance Specification.

5.4.26.3 Requirement

Functional state A

5.5 Mechanical requirements and tests

5.5.1 M-01 Free fall

5.5.1.1 Purpose

This test simulates the free fall of a component to the floor, as it may occur anytime throughout the process chain before the component is properly installed.

It is used to ensure that a component that may look visibly undamaged from the fall and therefore has been installed in the vehicle does not have any hidden damage or pre-existing faults (e.g., internal component detachments or cracks).

5.5.1.2 Test

See table 45.

Table 45 – Test parameters for M-01 Free fall

DUT operating mode	I.a
Drop height	1 m
Impact surface	Concrete floor
Test cycle	For each of the 3 DUTs, one DUT in both directions of one 3D spatial axis (1st DUT: $\pm X$, 2nd DUT: $\pm Y$, 3rd DUT: $\pm Z$)
Number of DUTs	3

5.5.1.3 Requirement

The DUT must be visually inspected, the result documented, and checked for loosened or rattling parts by shaking.

- If the DUT is not visibly damaged, the DUT must be fully functional after the test, and all parameters must be within the specifications. Proof of this must be provided by a P-03 parameter test (large) as per section 4.14.3.
- Concealed damage is not permissible.

5.5.2 M-02 Stone impact test

5.5.2.1 Purpose

This test simulates the mechanical load on the component due to stone impact.

It is used to verify the resistance of the component to flaw patterns, e.g., deformation or cracks.

5.5.2.2 Test

The test is carried out on the basis of DIN EN ISO 20567-1, Test Method B, with parameters as per table 46:

Table 46 – Test parameters for M-02 Stone impact test

DUT operating mode	I.b
Quantity of blasting medium	500 g
Test pressure	2 bar
Blasting material	Chilled iron grit as per DIN EN ISO 11124-2, grain size 4 mm to 5 mm
Test surface on DUT	All surfaces that are freely accessible on the vehicle
Impact angle	54° relative to blasting direction
Testing equipment	Multi grit tester as per DIN EN ISO 20567-1
Number of cycles	2
Number of DUTs	6

5.5.2.3 Requirement

The DUT must be fully functional before and after the test, and all parameters must meet the specifications. Proof of this must be provided by a P-02 parameter test (small) as per section 4.14.2.

The DUT must also be visually inspected and checked for loosened or rattling parts by shaking.

Changes/damage must be documented in the test report and evaluated together with the purchaser.

An evaluation based on the characteristics given in DIN EN ISO 20567-1 is not required.

5.5.3 M-03 Dust test

5.5.3.1 Purpose

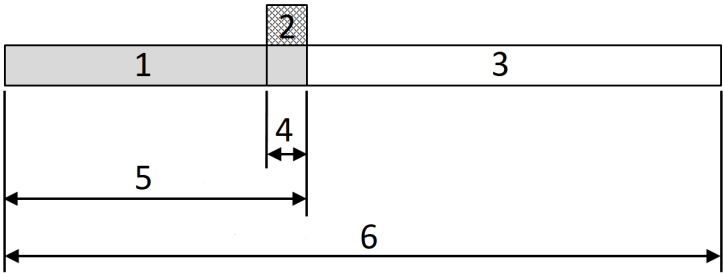
This test simulates the dust load on the component during vehicle operation.
It is used to verify the resistance of the component against electrical and mechanical flow patterns.

5.5.3.2 Test

Test procedure as per ISO 20653 with parameters as per table 47:

Table 47 – Test parameters for M-03 Dust test

DUT operating mode	For electrical/electronic components: operation _{min} for mechatronic components (e.g., for components with rotating parts, controls): intermittently operation _{max} and operation _{min} as per figure 25
Test setup	Vertical flow direction as per ISO 20653, Figure 1
Degree of protection to be achieved	As specified by the purchaser
Test duration	20 cycles of 20 min each
Number of DUTs	6



Legend

- 1 Operation_{max}
- 2 Dust
- 3 Operation_{min}
- 4 5 s
- 5 5 min
- 6 1 cycle / 20 min

Figure 25 – Test sequence for M-03 Dust test

When performing the test, the installation position of the component in the vehicle must be recreated. The test setup (as-installed position, covers, trim panels, situation during operation) must be suggested by the contractor, approved by the purchaser, and documented.

5.5.3.3 Requirement

The required degree of protection defined in the Performance Specification as per ISO 20653 must be achieved.

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by a P-02 parameter test (small) as per section 4.14.2.

The DUT must also undergo a visual inspection. Changes or damage must be documented in the test report and evaluated together with the purchaser.

5.5.4 M-04 Vibration test

5.5.4.1 Purpose

This test simulates the vibration load on the component in the driving operating situation.

It is used to verify the resistance of the component to flaw patterns such as component detachment or material fatigue.

5.5.4.2 Test

The test is carried out based on ISO 16750-3.

Test procedure as per DIN EN 60068-2-6 for sinusoidal vibration excitation and DIN EN 60068-2-64 for wide-band-shaped vibration excitation with parameters as per table 48:

Table 48 – Test parameters for general vibration

DUT operating mode	Intermittently $driving_{min}$ and $driving_{max}$ (see figure 26)
Superimposed temperature curve	Repeating as per figure 26 and table 49
Frequency sweep time for sinusoidal excitation	1 octave/min, logarithmic
Vibration profile A (for components installed on the engine/motor)	Vibration excitation, sinusoidal as per figure 27 and table 50 superimposed with vibration excitation, wide-band random vibration as per figure 28 and table 51
Vibration profile B (for components installed on the transmission)	Vibration excitation, sinusoidal as per figure 29 and table 52 superimposed with vibration excitation, wide-band random vibration as per figure 30 and table 53
Vibration profile C (for components installed at the decoupled intake plenum)	Vibration excitation, sinusoidal as per figure 31 and table 54
Vibration profile D (hang-on parts for components installed on sprung masses)	Vibration excitation, wide-band random vibration as per figure 32 and table 55
Vibration profile E for unsprung masses (chassis)	Vibration excitation, wide-band random vibration as per figure 33 and table 56
Number of DUTs	6

Components that are installed on an electric machine must be tested at least as per vibration profile D. However, this test profile does not take into account the specific vibration loads that emanate from an electric machine. However, in practice, these special vibration loads may occur and put strain on the component. Therefore, the specific vibration loads that emanate from an electric machine must be taken into account during the test. For this purpose, measurements are required on the electric machine in question.

When performing the test, the installation position of the component in the vehicle must be recreated.

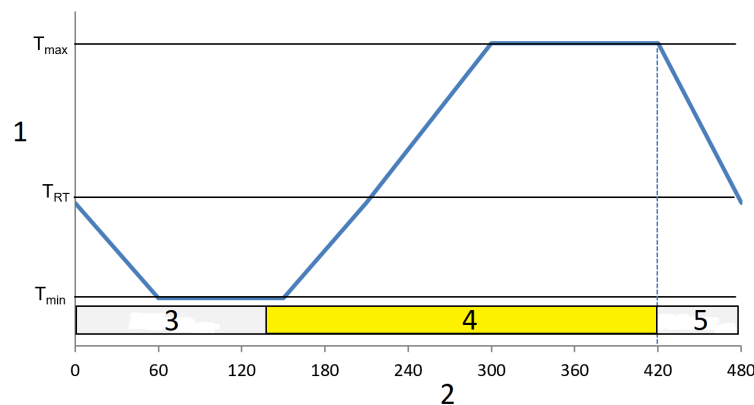
The manner of fastening connected lines (e.g. electrical wiring, coolant hoses, hydraulic lines) in the test setup must be defined with the purchaser.

For components that are installed on the bracket or vehicle by means of attenuators, it must be specified with the purchaser whether

- all DUTs with attenuators,
- all DUTs with attenuators or
- three DUTs in with attenuators and three DUTs without attenuators each need to be tested.

The sampling rate must be selected in such a way that interruptions and short circuits are detected.

Additional tests to verify the stability of the entire system, consisting of the component, bracket, and add-on parts in the ASSY must be agreed upon with the purchaser.



Legend

- 1 Temperature (see also table 49)
- 2 Time in min
- 3 Driving_{min}
- 4 Driving_{max} from 135 min to 420 min
- 5 Driving_{min}

Figure 26 – Vibration temperature curve

Table 49 – Vibration temperature curve

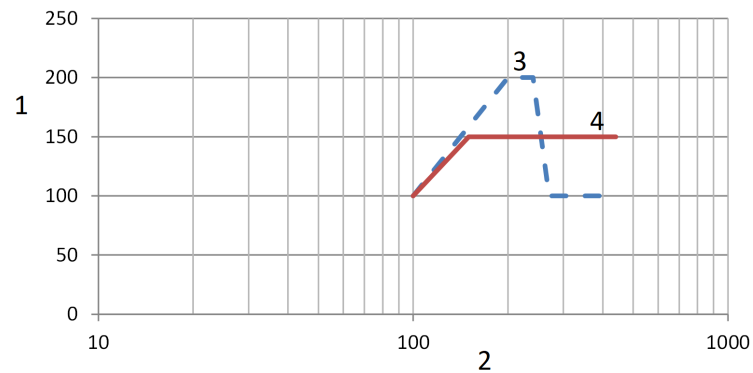
Time in min	Temperature
0	T_{RT}
60	T_{min}
150	T_{min}
300	T_{max}
410	T_{max}
480	T_{RT}

If a coolant circuit is present, the coolant temperature must track the respective test temperature to the limits $T_{cool,min}$ and $T_{cool,max}$. Only the ambient temperature is varied outside of the coolant temperature limits.

5.5.4.2.1 Vibration profile A (components installed on the engine/motor)

Table 50 – Vibration test parameters, sinusoidal for engine-mounted parts

Vibration excitation	Sinusoidal	
Test duration for each spatial axis	22 h	
Vibration profile	<p>Curve 1 is for components mounted to engines with 5 or fewer cylinders.</p> <p>Curve 2 is for components mounted to engines with 6 or more cylinders.</p> <p>The curves are combined for components that can be used in both cases.</p>	
Curve 1 in figure 27	Frequency in Hz	Amplitude of acceleration in m/s^2
	100	100
	200	200
	240	200
	270	100
	440	100
Curve 2 in figure 27	Frequency in Hz	Amplitude of acceleration in m/s^2
	100	100
	150	150
	440	150
Combination	Frequency in Hz	Amplitude of acceleration in m/s^2
	100	100
	150	150
	200	200
	240	200
	255	150
	440	150



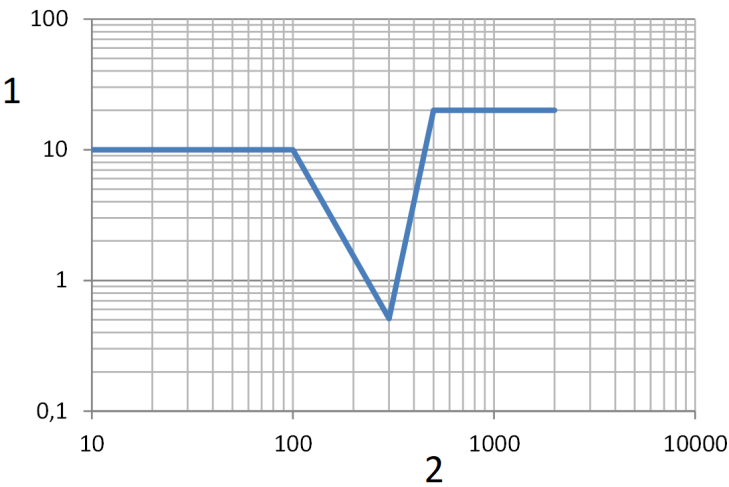
Legend

- 1 Amplitude of acceleration in m/s^2
- 2 Frequency in Hz
- 3 Curve 1
- 4 Curve 2

Figure 27 – Vibration profile, sinusoidal for engine-mounted parts

Table 51 – Vibration test parameters, wide-band random vibration for engine-mounted parts

Vibration excitation	Wide-band random vibration	
Test duration for each spatial axis	22 h	
RMS value of acceleration	181 m/s^2	
Vibration profile figure 28	Frequency in Hz	Power density spectrum in $(\text{m/s}^2)^2/\text{Hz}$
	10	10
	100	10
	300	0,51
	500	20
	2 000	20



Legend

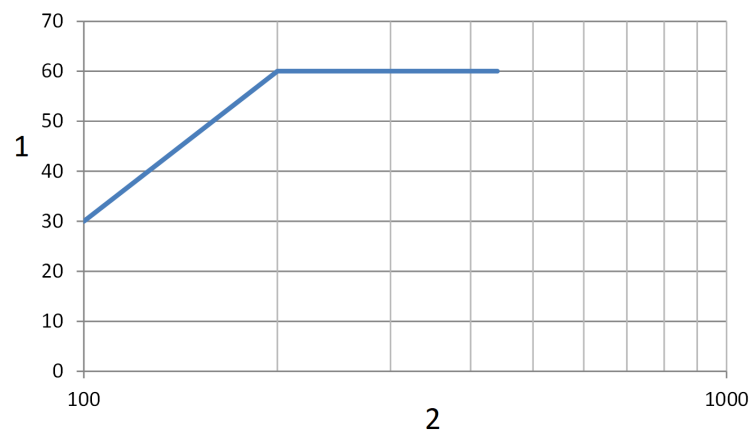
- 1 Power density spectrum in (m/s²)²/Hz
- 2 Frequency in Hz

Figure 28 – Vibration profile, wide-band random vibration for engine-mounted parts

5.5.4.2.2 Vibration profile B (components installed on the transmission)

Table 52 – Vibration test parameters, sinusoidal for transmission-mounted parts

Vibration excitation	Sinusoidal	
Test duration for each spatial axis	22 h	
Vibration profile figure 29	Frequency in Hz	Amplitude of acceleration in m/s²
	100	30
	200	60
	440	60



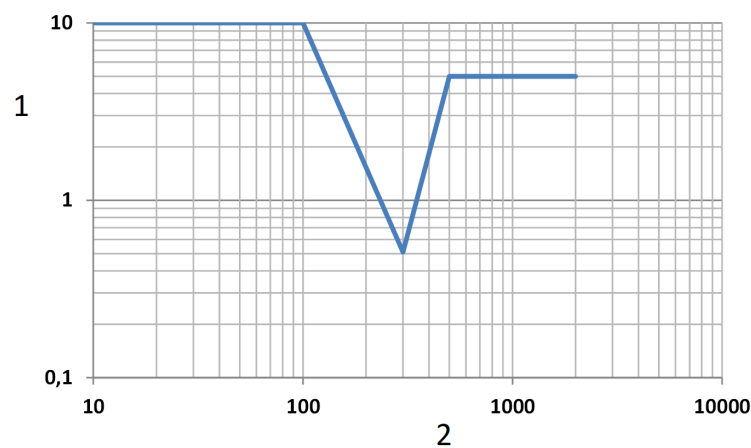
Legend

- 1 Amplitude of acceleration in m/s²
2 Frequency in Hz

Figure 29 – Vibration profile, sinusoidal for transmission-mounted parts

Table 53 – Test parameters - vibration, wide-band random vibration for transmission-mounted parts

Vibration excitation	Wide-band random vibration	
Test duration for each spatial axis	22 h	
RMS value of acceleration	96,6 m/s ²	
Vibration profile figure 30	Frequency in Hz	Power density spectrum in (m/s ²) ² /Hz
	10	10
	100	10
	300	0,51
	500	5
	2 000	5



Legend

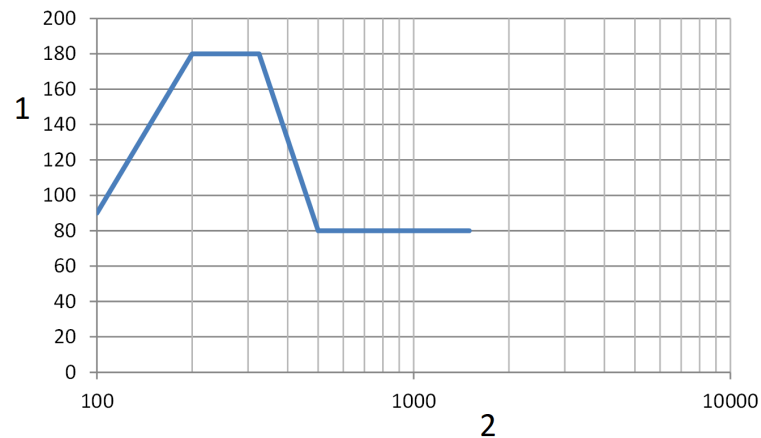
- 1
- Power density spectrum in (m/s²)²/Hz
- 2
- Frequency in Hz

Figure 30 – Vibration profile, sinusoidal for transmission-mounted parts

5.5.4.2.3 Vibration profile C (components installed at the decoupled intake plenum)

Table 54 – Test parameters, sinusoidal for components at the decoupled intake plenum

Vibration excitation	Sinusoidal	
Test duration for each spatial axis	22 h	
Vibration profile figure 31	Frequency in Hz	Amplitude of acceleration in m/s²
	100	90
	200	180
	325	180
	500	80
	1 500	80



Legend

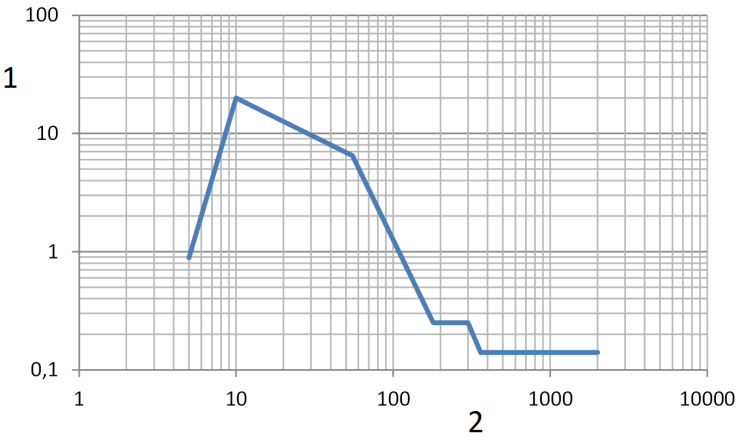
- 1 Amplitude of acceleration in m/s^2
2 Frequency in Hz

Figure 31 – Vibration profile, sinusoidal for transmission-mounted parts

5.5.4.2.4 Vibration profile D (components installed on sprung masses [body])

Table 55 – Test parameters, wide-band random vibration for sprung masses

Vibration excitation	Wide-band random vibration	
Test duration for each spatial axis	8 h	
RMS value of acceleration	30,8 m/s^2	
Vibration profile figure 32	Frequency in Hz	Power density spectrum in $(\text{m/s}^2)^2/\text{Hz}$
	5	0,884
	10	20
	55	6,5
	180	0,25
	300	0,25
	360	0,14
	1 000	0,14
	2 000	0,14



Legend

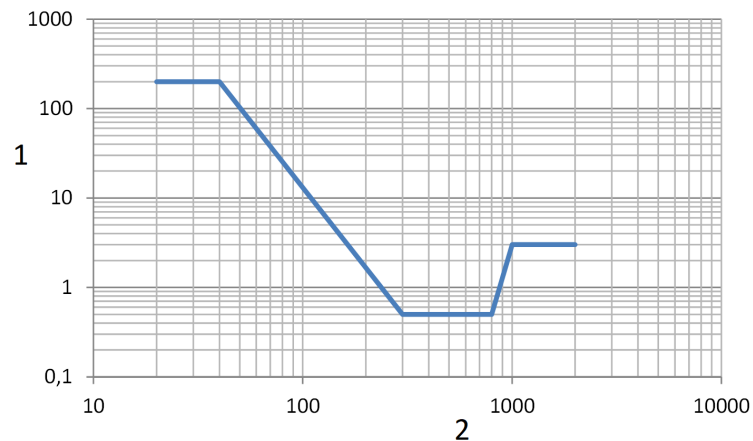
- 1
- Power density spectrum in $(m/s^2)^2/Hz$
- 2
- Frequency in Hz

Figure 32 – Vibration profile, wide-band random vibration for sprung masses

5.5.4.2.5 Vibration profile E (components installed on unsprung masses (wheel, suspension))

Table 56 – Test parameters, wide-band random vibration for unsprung masses

Vibration excitation	Wide-band random vibration	
Test duration for each spatial axis	8 h	
RMS value of acceleration	107,3 m/s ²	
Vibration profile figure 33	Frequency in Hz	Power density spectrum in $(m/s^2)^2/Hz$
	20	200
	40	200
	300	0,5
	800	0,5
	1 000	3
	2 000	3



Legend

- 1 Power density spectrum in $(m/s^2)^2/Hz$
- 2 Frequency in Hz

Figure 33 – Vibration profile, wide-band random vibration for unsprung masses

5.5.4.3 Requirement

The **DUT** must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-03 parameter test (large) as per section 4.14.3.

The **DUT** must also be visually inspected and checked for loosened or rattling parts by shaking.

5.5.5 M-05 Mechanical shock

5.5.5.1 Purpose

This test simulates the mechanical load on the component, e.g., when driving over curbs or in the event of any car accidents.

It is used to verify the resistance of the component to flaw patterns such as cracks or component detachment.

5.5.5.2 Test

Test procedure as per DIN EN 60068-2-27 with parameters as per table 57:

Table 57 – Test parameters for M-05 Mechanical shock

DUT operating mode	Intermittently driving _{min} and driving _{max}
Peak acceleration	500 m/s ²
Shock duration	6 ms
Shape of shock pulse	Half-sine
Number of shocks per direction (±X, ±Y, ±Z)	10
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.

The test must be performed without brackets or add-on parts. The manner of fastening connected lines (e.g. electrical wiring, coolant hoses, hydraulic lines) in the test setup must be defined with the purchaser.

For components that are installed on the bracket or vehicle by means of attenuators, it must be specified with the purchaser whether

- all DUTs with attenuators,
- all DUTs with attenuators or
- three DUTs in with attenuators and three DUTs without attenuators each

need to be tested.

The time between the shock pulses must be long enough to ensure complete decay of the previous vibration.

5.5.5.3 Requirement

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-02 parameter test (small) as per section 4.14.2.

The DUT must also be visually inspected and checked for loosened or rattling parts by shaking.

5.5.6 M-06 Mechanical shock durability testing

5.5.6.1 Purpose

This test simulates the acceleration forces of components that are installed in doors, hoods, or tailgates/trunk lids and are exposed to high accelerations during opening and closing.

It is used to verify the resistance of the component to flaw patterns such as component detachment or material fatigue.

5.5.6.2 Test

Test procedure as per DIN EN 60068-2-27 with parameters as per table 58:

Table 58 – Test parameters for M-06 Shock durability testing

DUT operating mode	Operation _{max}	
Peak acceleration	300 m/s ²	
Shock duration	6 ms	
Shape of shock pulse	Half-sine	
Number of shocks	Point of use	Number of shocks
	Driver door	100 000
	Front passenger door and rear doors	50 000
	Trunk lid/tailgate	30 000
	Hood	3 000
	If the component is installed in several installation areas, the one with the highest number of shocks must be selected.	
Installation position	The DUT must be mounted on the test device according to its installed condition in the vehicle.	
Number of DUTs	6	

5.5.6.3 Requirement

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-02 parameter test (small) as per section 4.14.2.

The DUT must also be visually inspected and checked for loosened or rattling parts by shaking.

5.5.7 M-07 Coolant circuit pressure pulsation test

5.5.7.1 Purpose

This test simulates the load on the component due to coolant pressure fluctuations as well as statuses during the post-heating phase and when filling the coolant system with a vacuum. It must be applied exclusively to components that are connected to a coolant circuit. It is used to verify the mechanical strength of the components affected by pressure fluctuations in the coolant circuit (e.g., cooling plates of the power module).

5.5.7.2 Test

See table 59.

Table 59 – Test parameters for M-07 Coolant circuit pressure pulsation test

DUT operating mode	I.b
Test procedure	<p>Part 1 - Vacuum test (without test medium): Test pressure P: 0,02 (-0,01) bar_{abs} Test temperature: T_{RT} Test cycle: <ul style="list-style-type: none"> – Set the DUT to the test pressure using the pump. – Shut off the pump. – Hold time: 10 s – DUT ventilation Number of test cycles: 4 Criterion for tightness: a pressure increase within the hold time of ≤ 1 mbar</p> <p>Part 2 - Pressure pulsation test: Minimum test pressure P_{min}: 0,5 (-0,1) bar_{abs} Maximum test pressure P_{max}: 2,0 (+0,1) bar_{abs} Pressure pulsation frequency: 25 1/min to 35 1/min Number of pressure changes: 100 000 Test temperature: T_{cool,max}</p> <p>Part 3 - Positive pressure test (without test medium): Test pressure P: 4,0 (+0,1) bar_{abs} Test temperature: T_{cool,max} Test cycle: <ul style="list-style-type: none"> – Set the DUT to the test pressure using the pump. – Shut off the pump. – Hold time: 10 s – Release pressure on the DUT Number of test cycles: 4 Criterion for tightness: drop in pressure within the hold time ≤ 4 mbar</p>
Test medium	This must be agreed upon with the purchaser, specifically for each component.
Number of DUTs	6

5.5.7.3 Requirement

The DUT must be fully functional before and after the test, and all parameters must meet the specifications. Proof of this must be provided by a P-03 parameter test (large) as per [section 4.14.3](#).

5.5.8 M-08 Protection against foreign bodies - IP0x to IP4x, A, B, C, D

5.5.8.1 Purpose

This test is used to verify that the component is sufficiently protected against foreign body ingress.

5.5.8.2 Test

Test procedure as per ISO 20653 with parameters as per table 60:

**Table 60 – Test parameter for M-08
Protection against foreign bodies - IP0x to
IP4x, A, B, C, D**

DUT operating mode	I.b
Number of DUTs	6

The test must be documented with photographs.

5.5.8.3 Requirement

The required degree of protection defined in the Performance Specification as per ISO 20653 must be achieved.

Functional state A

5.5.9 M-09 Leak test

5.5.9.1 Purpose

The required tightness of a component in terms of its self-contained electronics space relative to the environment or other spaces, such as the coolant duct of a coolant circuit, is described as a tightness requirement. The tightness requirement is defined as a limit leakage rate and must be verified by means of a leak test.

Adherence to the defined component-specific limit leakage rate of the electronics space of a component is verified by a leak test.

5.5.9.2 Test

The air leakage rate of the DUT must be determined by using common measuring methods (e.g., absolute pressure, differential pressure, mass airflow or volumetric flow rate measurement). The measuring method must be agreed upon with the purchaser.

See table 61.

Table 61 – Test parameters for M-09 Leak test

Operating mode of the DUT	This must be agreed upon with the purchaser. If an operating mode has not been specified, operating mode I.c must be used.
Test procedure	A defined test pressure is applied to the component via an access point (e.g., venting element). The air leakage rate is recorded using measuring technology after a stabilization period. Since the design and application determine which pressure of a medium the component will be exposed to in real-life operation, the test pressure corresponding to the most severe use case in the field must be selected. This may also be a vacuum. If it must be assumed that the sealing system will behave differently in positive pressure and a vacuum (e.g., pressing on sealing lips), the test must be carried out in positive pressure and a vacuum. The DUT may not be exposed to any temperature fluctuations during the measurement.
Test temperature	T _{RT}
Test pressure	This must be agreed upon with the purchaser. If a test pressure is not specified, a test pressure of Δ 300 mbar must be applied.
Number of DUTs	6

5.5.9.3 Requirement

The DUT must be fully functional before and after the test, and all parameters must meet the specifications.

The measured air leakage rate must not exceed the defined, component-specific limit leakage rate, and must be documented in the test report. If a component-specific leakage value has not been specified, a leakage value of 1 cm³/min (0,0167 mbar l/s) must apply, which must not be exceeded. Changes in the air leakage rate must be evaluated and must be documented in the test report.

The leak test must be carried out as part of the P-03 Parameter test (large) as per section 4.14.3 at T_{RT} .

5.6 Climatic requirements and tests

5.6.1 K-01 High-/low-temperature aging

5.6.1.1 Purpose

This test simulates the thermal load on the component during storage and transport.

It is used to verify the resistance to storage at high or low temperatures, e.g., during component transport (by plane, shipping container).

If the test is carried out at the start of a test sequence, it is also used to adjust all components to the same initial conditions.

5.6.1.2 Test

See table 62.

Table 62 – Test parameters for K-01 High-/low-temperature storage

DUT operating mode	I.a
Test duration and test temperature	2 cycles of 24 h each (each consisting of 12 h of aging at T_{\min} and 12 h of aging at T_{\max})
Temperature gradient	max. 4 K/min
Number of DUTs	As specified in the test sequence plan in the Performance Specification

5.6.1.3 Requirement

The DUT must be fully functional before and after the test, and all parameters must meet the specifications. Proof of this must be provided by a P-03 parameter test (large) as per section 4.14.3.

The DUT must also be visually inspected and checked for loosened or rattling parts by shaking.

5.6.2 K-02 Incremental temperature test

5.6.2.1 Purpose

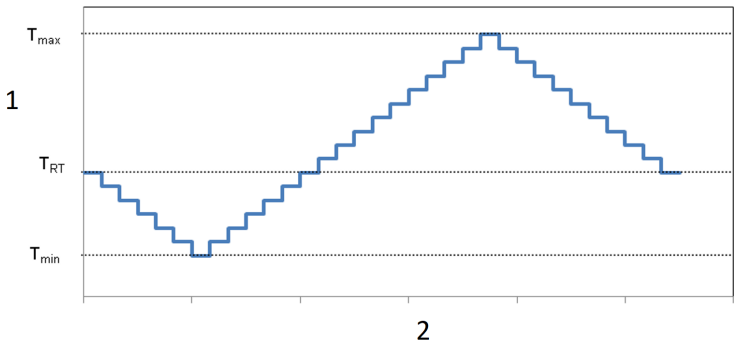
This test simulates operation of the component at different ambient temperatures. It is used to verify the resistance of the component against malfunctions that may occur within a small ambient temperature range interval, and the start-up behavior of the components over the entire ambient temperature range.

5.6.2.2 Test

See table 63.

Table 63 – Test parameters for K-02 Incremental temperature test

DUT operating mode	During the P-01 parameter test (function check) as per section 4.14.1 operation _{max} , otherwise parking _{min}
Test temperature	The DUTs must be exposed to a temperature profile as per figure 34. The temperature change per increment is 5 K.
Test sequence	The DUT must be held at every temperature level until it has reached a constant temperature throughout (see section 4.6). Then a P-01 parameter test (function check) must be carried out as per section 4.14.1.
Number of DUTs	As specified in the test sequence plan in the Performance Specification, but at least 6



Legend

- 1 Temperature
- 2 Time

Figure 34 – Temperature profile for incremental temperature test

If a coolant circuit is present, the coolant temperature must track the respective test temperature to the limits $T_{cool,min}$ and $T_{cool,max}$. Only the ambient temperature is varied outside of the coolant temperature limits.

5.6.2.3 Requirement

All DUT parameters must be within the specification for each P-01 Parameter test (function check) as per section 4.14.1.

5.6.3 K-03 Low-temperature operation

5.6.3.1 Purpose

This test simulates the load on the component at low temperatures.

It is used to verify component functionality after a long parking time or driving time at extremely low temperatures.

5.6.3.2 Test

Test procedure as per DIN EN 60068-2-1, Test Ab with parameters as per table 64:

Table 64 – Test parameters for K-03 Low-temperature operation

DUT operating mode	12 h parking _{min} (t.30 component V _{opmin}) 12 h operation _{max} at V _{opmin} 12 h parking _{min} (t.30 component V _{op}) 12 h operation _{max} at V _{op}
Test duration	48 h
Test temperature	T _{min}
Number of DUTs	6

The test as per DIN EN 60068-2-1, test Ab, must also be carried out for components that dissipate heat.

If a coolant circuit is present, the minimum coolant temperature T_{cool,min} must be set.

For components with high power loss, an increase in the test chamber temperature above T_{min} as a result of self-heating is permissible during the test in operating mode Operation_{max} subject to agreement between the contractor and the purchaser.

5.6.3.3 Requirement

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-02 parameter test (small) as per section 4.14.2.

5.6.4 **K-04 Repainting temperature**

5.6.4.1 **Purpose**

This test simulates the load on the component during repainting.
It is used to verify the resistance of the component against thermally induced flaw patterns, such as cracking in solder joints, adhesive joints, bonded joints, and welded joints, and on seals and housings.

5.6.4.2 **Test**

See table 65.

Table 65 – Test parameters for K-04 Repainting temperature

DUT operating mode	Parking _{min}
Test duration and test temperature	60 min at 90 °C
Number of DUTs	6

If a coolant circuit is present, the temperature of the idle coolant must be set to T_{RT}.

5.6.4.3 **Requirement**

The DUT must be fully functional before and after the test, and all parameters must meet the specifications. Proof of this must be provided by a P-02 parameter test (small) as per section 4.14.2.

5.6.5 K-05 Thermal shock (component)

5.6.5.1 Purpose

This test simulates the thermal load on the component as a result of abrupt changes in temperature during vehicle operation.

It is used to verify the resistance of the component against thermally induced flaw patterns, such as cracking in solder joints, adhesive joints, bonded joints, and welded joints, and on seals and housings.

5.6.5.2 Test

Test procedure as per DIN EN 60068-2-14 with parameters as per table 66:

Table 66 – Test parameters for K-05 Thermal shock (component)

DUT operating mode	I.b
Minimum temperature/temperature of the cold test bath	T_{\min}
Maximum temperature/temperature of the hot test bath	T_{\max}
Hold time at minimum/maximum temperature	15 min after having reached a constant temperature throughout (see section 4.6)
Transfer time (air-to-air, medium-to-medium)	≤ 30 s
Test fluid for test Nc	Fluid in which the component is operated in the vehicle
Test	As per DIN EN 60068-2-14, Test Na for components that are not continuously operated in a fluid as per DIN EN 60068-2-14, Test Nc for components that are continuously operated in a fluid (IP X8) The DUT must be immersed here in such a way that all sides of the DUT are surrounded by at least 25 mm of the test fluid.
Number of cycles	100
Number of DUTs	6

5.6.5.3 Requirement

The DUT must be fully functional before and after the test, and all parameters must meet the specifications. Proof of this must be provided by a P-03 parameter test (large) as per section 4.14.3.

Additionally for the medium-to-medium test:

The fluid must not penetrate the DUT. The DUT must not be opened until after the entire test sequence has been completed as per the test sequence plan (section 5.3).

5.6.6 K-06 Salt spray test with operation, vehicle exterior

5.6.6.1 Purpose

This test simulates the load on the component in a saline atmosphere with saline water, as it may occur in certain regions of the world and in wintry road conditions.

It is used to verify the resistance of the component against any malfunctions when exposed to a salt load, e.g., from short circuits and leakage currents due to the ingress of salt into the component.

5.6.6.2 Test

Test procedure as per DIN EN IEC 60068-2-11 with parameters as per table 67:

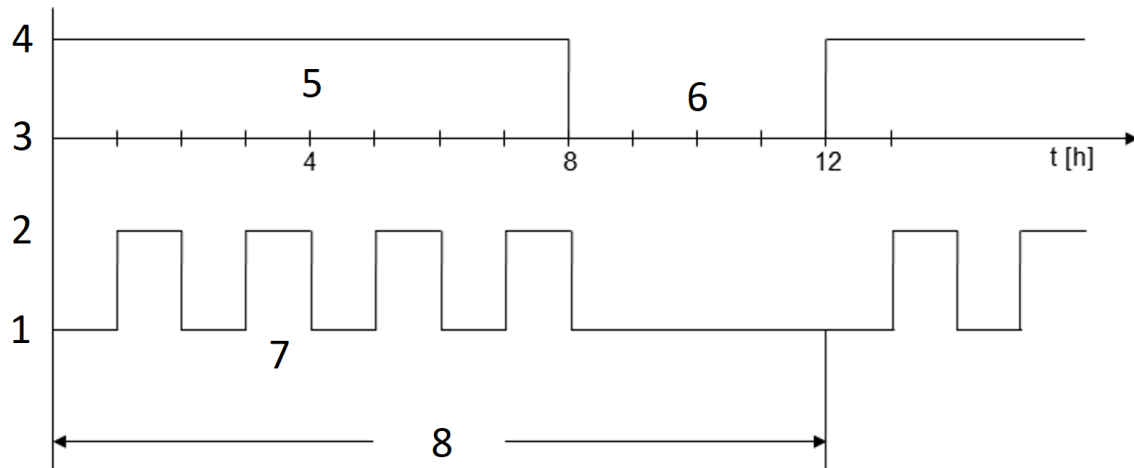
Table 67 – Test parameters for K-06 Salt spray test with operation, vehicle exterior

DUT operating mode	During the spraying phase: intermittently 1 h parking _{min} and 1 h operation _{max} each During the idle phase: parking _{min}
Test temperature	35 °C
Test cycle	Each test cycle consists of an 8-h spraying phase and a 4-h resting period as per figure 35.
Number of cycles	12 cycles For components with increased requirements for tightness as per section 5.5.9 (e.g., exposure of parked vehicle to water), the number of cycles must be adapted on a component-specific basis.
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.

It is not permissible to clean the DUTs after the test.

If a coolant circuit is present, the coolant temperature must be set to the test temperature.



Legend

- 1 Parking_{min}
- 2 Operation_{max}
- 3 OFF
- 4 ON
- 5 Spraying phase
- 6 Resting period
- 7 Electrical operation
- 8 1 cycle

Figure 35 – Salt spray test with operation, vehicle exterior - spraying phases

5.6.6.3 Requirement

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-02 parameter test (small) as per section 4.14.2.

5.6.7 K-07 Salt spray test with operation, vehicle interior

5.6.7.1 Purpose

This test simulates the load on the component in a saline atmosphere, as it may occur in certain regions of the world.

It is used to verify the resistance of the component against any malfunctions when exposed to a salt load, e.g., from short circuits and leakage currents due to the ingress of salt into the components.

5.6.7.2 Test

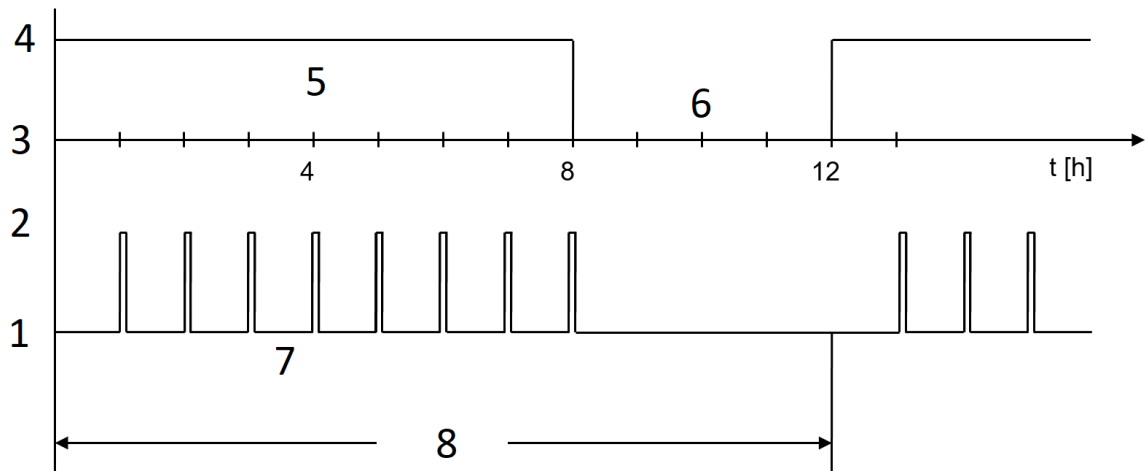
Test procedure as per DIN EN IEC 60068-2-11 with parameters as per table 68:

Table 68 – Test parameters for K-07 Salt spray test with operation, vehicle interior

DUT operating mode	During the spraying phase: intermittently 55 min parking _{min} and 5 min operation _{max} each During the idle phase: parking _{min}
Test temperature	35 °C
Test cycle	Each test cycle consists of an 8-h spraying phase and a 4-h resting period as per figure 36.
Number of cycles	2
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated. The test setup (as-installed position, covers, trim panels, situation during operation) must be suggested by the contractor, agreed upon with the purchaser, and documented.

If a coolant circuit is present, the coolant temperature must be set to the test temperature.



Legend

- 1 Parking_{min}
- 2 Operation_{max}
- 3 OFF
- 4 ON
- 5 Spraying phase
- 6 Resting period
- 7 Electrical operation
- 8 1 cycle

Figure 36 – Salt spray test with operation, vehicle interior – spraying phases

5.6.7.3 Requirement

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-03 parameter test (large) as per section 4.14.3.

5.6.8 K-08 Damp heat, cyclic

5.6.8.1 Purpose

This test simulates the thermal load on the component by cyclic temperature changes with high humidity during vehicle operation.

It is used to verify the resistance of the component against damp heat.

5.6.8.2 Test

Test procedure as per DIN EN 60068-2-30 with parameters as per table 69:

Table 69 – Test parameters for K-08 Damp heat, cyclic

DUT operating mode	During the P-01 parameter test (function check) operation _{max} , otherwise parking _{min}
Total test duration	144 h
Test variant	Variant 1
Maximum test temperature	55 °C
Number of cycles	6
Number of DUTs	6

A P-01 parameter test (function check) must be carried out in each case once the maximum and minimum test temperature has been reached.

If a coolant circuit is present, the coolant temperature must track the respective test temperature to the limits $T_{cool,min}$ and $T_{cool,max}$. Only the ambient temperature is varied outside of the coolant temperature limits.

When performing the test, the installation position of the component in the vehicle must be recreated.

5.6.8.3 Requirement

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-03 parameter test (large) as per section 4.14.3.

5.6.9 K-09 Damp heat, cyclic (with frost)

5.6.9.1 Purpose

This test simulates the thermal load on the component (including frost) by cyclic temperature changes with high humidity during vehicle operation.

It is used to verify the resistance of the components against damp heat.

5.6.9.2 Test

Test procedure as per DIN EN 60068-2-38 with parameters as per table 70:

Table 70 – Test parameters for K-09 Damp heat, cyclic (with frost)

DUT operating mode	Intermittently 40 min parking _{min} and 10 min operation _{max} each The contractor must come to an agreement with the purchaser as to whether the duration in the operation _{max} operating mode can be shortened to the duration required to test the total functionality of the component for components that can heat themselves to very high temperatures. In this case, the cycle duration of 50 min must remain in place.
Total test duration	240 h
Number of cycles	10
Test cycle sequence	The first 5 cycles must be carried out with a cold phase and the remaining cycles without a cold phase.
Number of DUTs	6

If a coolant circuit is present, the coolant temperature must track the respective test temperature to the limits $T_{cool,min}$ and $T_{cool,max}$. Only the ambient temperature is varied outside of the coolant temperature limits.

When performing the test, the installation position of the component in the vehicle must be recreated.

5.6.9.3 Requirement

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications (functional state A). Proof of this must be provided by continuously monitoring key parameters and a P-03 parameter test (large) as per section 4.14.3.

5.6.10 K-10 Water protection – IPX0 to IPX6K

5.6.10.1 Purpose

This test simulates the load on the component when exposed to water.

It is used to verify component functionality, e.g., when exposed to condensate water, rain, or splash water.

5.6.10.2 Test

Test procedure as per ISO 20653 with parameters as per table 71:

Table 71 – Test parameters for K-10 Water protection - IPX0 to IPX6K

DUT operating mode	intermittently 1 min operation _{min} and 1 min operation _{max} each
Required degree of protection	As defined in the Performance Specification
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.

5.6.10.3 Requirement

The required degree of protection defined in the Performance Specification as per ISO 20653 must be achieved.

The ingress of water is not permissible. The DUT must not be opened until after completion of the entire test sequence.

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-02 parameter test (small) as per section 4.14.2.

5.6.11 K-11 High-pressure/steam-jet cleaning

5.6.11.1 Purpose

This test simulates the load on the component when subjected to water during vehicle cleaning. It is used to verify component functionality when exposed to high-pressure cleaning/steam-jet cleaning.

5.6.11.2 Test

Test procedure as per ISO 20653 with parameters as per table 72:

Table 72 – Test parameters for K-11 High-pressure/steam-jet cleaning

DUT operating mode	Parking _{min}
Required degree of protection	IP X9K
Water pressure	The minimum pressure of the steam jet is 10 000 kPa (100 bar), measured directly at the nozzle.
Water temperature	80 °C
Procedure	The DUT must be exposed to the water jet from every spatial direction that is freely accessible on the vehicle.
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.

5.6.11.3 Requirement

Degree of protection IP X9K as per ISO 20653 must be achieved.

The ingress of water is not permissible. The DUT must not be opened until after the entire test sequence has been completed as per the test sequence plan (section 5.3).

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-02 parameter test (small) as per section 4.14.2.

5.6.12 K-12 Thermal shock with splash water

5.6.12.1 Purpose

This test simulates the load on the component when exposed to splash water when driving through puddles.

It is used to verify component functionality when subjected to abrupt cooling by water.

5.6.12.2 Test

See table 73.

Table 73 – Test parameters for K-12 Thermal shock with splash water

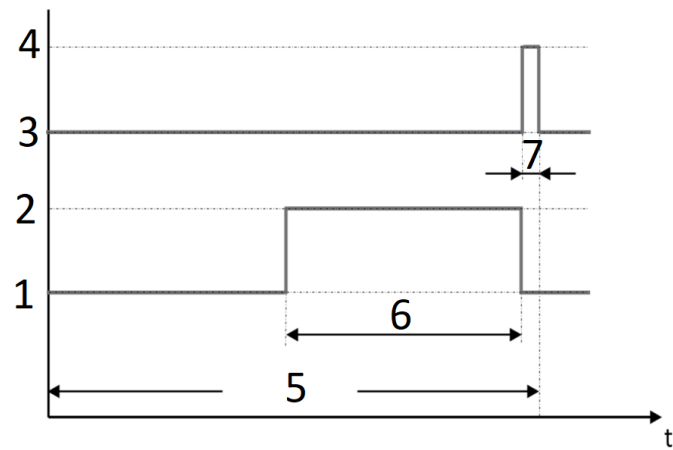
DUT operating mode	Intermittently $driving_{min}$ and $driving_{max}$ (see figure 37)
Test procedure	Heat the DUT up to the test temperature Then subject the DUT to a cyclic splash test as per figure 37. The DUT must be splashed over its entire width.
Cycle duration	30 min
Test temperature	T_{max}
Test medium for splashing	Tap water containing Arizona dust, fine, in a weight percentage of 3% as per ISO 12103-1. Permanent mixing must be ensured.
Splash water temperature	0 °C to +4 °C
Splash nozzle	See figure 38.
Splash duration	3 s
Water discharge	3 l to 4 l per splash/nozzle
Distance between nozzle and DUT	300 mm to 350 mm
Number of cycles	100
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.

The test setup (as-installed position, covers, trim panels, situation during operation) must be suggested by the contractor, agreed upon with the purchaser, and documented.

If a coolant circuit is present, the coolant temperature must track the respective test temperature up to the limit $T_{cool,max}$. Only the ambient temperature is varied above the coolant temperature limit.

Test setup as per figure 39



Legend

- 1 Driving_{min} operating mode
- 2 Driving_{max} operating mode
- 3 Splash off
- 4 Splash on
- 5 t_1 (1 cycle) = 30 min
- 6 t_2 = 14 min 57 s
- 7 t_3 = 3 s

Figure 37 – Splash water test - splash times

Dimensions in mm

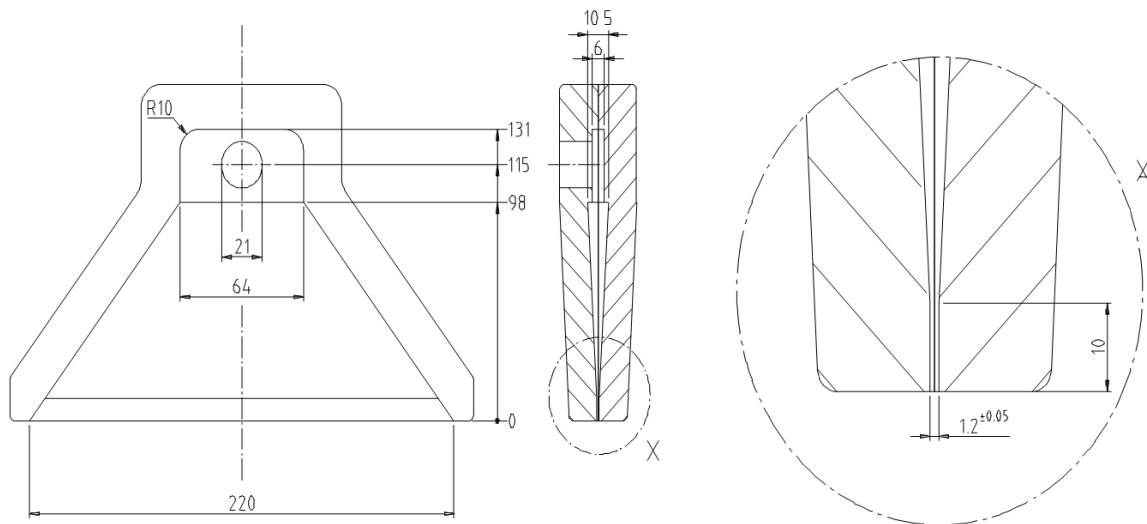
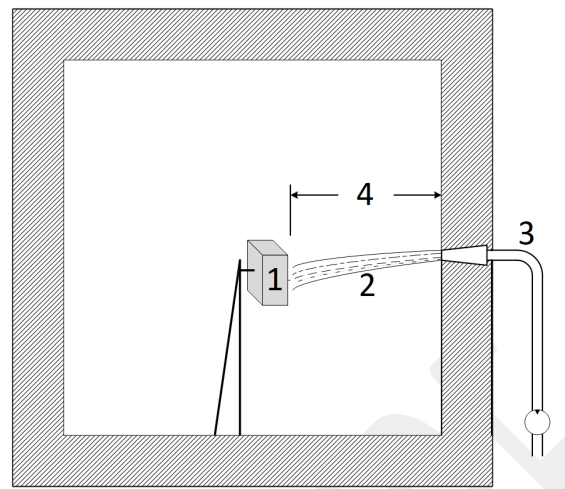


Figure 38 – Splash water test - splash nozzle



Legend

- | | |
|---|------------------|
| 1 | DUT |
| 2 | Splashing |
| 3 | Splash nozzle |
| 4 | 300 mm to 350 mm |

Figure 39 – Splash water test setup

5.6.12.3 Requirement

The ingress of water is not permissible. The DUT must not be opened until after completion of the entire test sequence.

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-02 parameter test (small) as per section 4.14.2.

5.6.13 K-13 Thermal shock – immersion

5.6.13.1 Purpose

This test simulates the load on the component when immersed in water.

The test is used to verify component functionality when subjected to immediate cooling due to immersion of the heated component.

5.6.13.2 Test

Test procedure as per ISO 20653 with parameters as per table 74:

Table 74 – Test parameters for K-13 Thermal shock – immersion

DUT operating mode	Driving _{max}
Required degree of protection	IP X7
Test procedure	Heat DUT up to $T_{op,max}$ Hold DUT at $T_{op,max}$ until it has reached a constant temperature throughout (see section 4.6) plus 15 min Fully immerse the DUT into the test medium within ≤ 5 s The DUT must be surrounded by least 25 mm of test medium on all sides.
Test medium	Cold water at 0 °C with a salt content of 5%
Immersion duration	5 min
Number of cycles	20
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.

If a coolant circuit is present, the coolant temperature must track the respective test temperature up to the limit $T_{cool,max}$. Only the ambient temperature is varied above the coolant temperature limit.

5.6.13.3 Requirement

The ingress of water is not permissible. The DUT must not be opened until after the entire test sequence has been completed as per the test sequence plan (section 5.3).

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-02 parameter test (small) as per section 4.14.2.

5.6.14 K-14 Damp heat, constant

5.6.14.1 K-14 a Damp heat, constant - severity 1

5.6.14.1.1 Purpose

This test simulates the load on the component due to damp heat.

It is used to verify the resistance of the component to flaw patterns that are caused by damp heat, e.g. corrosion, swelling, and degradation of plastics, sealing and potting compounds.

5.6.14.1.2 Test

Test procedure as per DIN EN 60068-2-78 with parameters as per table 75:

**Table 75 – Test parameters for K-14 a
Damp heat, constant - Severity 1**

DUT operating mode	Parking _{min}
Test temperature	40 °C
Test humidity	93% relative humidity
Test duration	21 days
Number of DUTs	6

5.6.14.1.3 Requirement

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-03 parameter test (large) as per section 4.14.3.

In addition, a P-01 parameter test (function check) must be carried out every seven days as per section 4.14.1.

5.6.14.2 K-14 b Damp heat, constant - severity 2

5.6.14.2.1 Purpose

This test simulates the load on the component due to damp heat during the vehicle service life in the form of an accelerated test.

It is used to verify the quality and reliability of the component in terms of resistance against flaw patterns caused by damp heat, e.g., corrosion, swelling, and degradation of plastics, sealing and potting compounds.

5.6.14.2.2 Test

Test procedure as per DIN EN 60068-2-78 with parameters as per table 76:

Table 76 – Test parameters for K-14 b Damp heat, constant - severity 2

DUT operating mode	Intermittent operation, 47 h parking _{min} and 1 h operation _{max} each, repeatedly up to the end of the test duration
Test temperature	65 °C
Test humidity	93% relative humidity
Test duration	As defined in the Performance Specification as per section F.1 „Lawson model“
Number of DUTs	6

If a coolant circuit is present, the coolant temperature must track the respective test temperature up to the limit $T_{cool,max}$. Only the ambient temperature is varied above the coolant temperature limit.

A check must be done to see whether the physical limits of the materials used in the components have been exceeded (e.g., hydrolysis of plastics) due to the highly accelerated testing using the test parameters of 65 °C and 93% relative humidity prior to carrying out this service life test. If required, the contractor and purchaser must agree upon the adaptation of the test temperature and test humidity while increasing the test duration according to the „Lawson“ model (e.g., to 55 °C and 93% relative humidity) so that the physical limits of the materials being used are not exceeded during the test. However, the test severity must remain in place throughout the test. The test humidity must not exceed a value of 93% relative humidity.

It must be ensured that no condensation occurs on the DUT during the test (also no localized condensation).

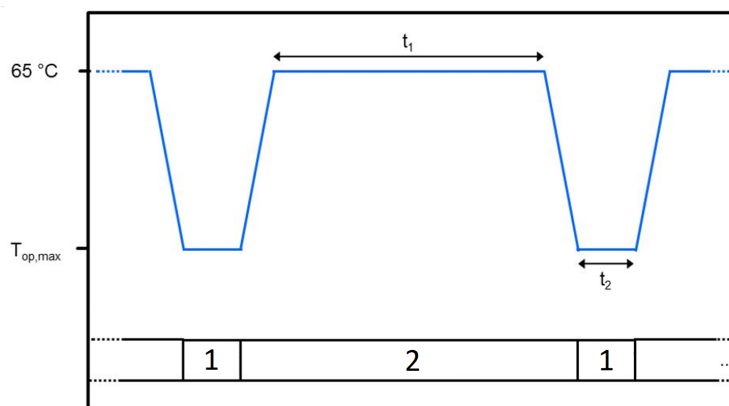
5.6.14.2.3 Deviating test for components with reduced performance at high temperatures

For components with reduced performance (e.g., reduction of LCD backlighting) in the event of high temperatures at or above $T_{op,max}$ ($T_{op,max} < 65$ °C), the test must not be carried out at a constant temperature of 65 °C - deviating from table 76 - but rather with the following parameters (see table 77).

Table 77 – Test parameters for K-14 damp heat, constant for components with reduced performance at high temperatures

DUT operating mode	Intermittent operation as per figure 40
Test temperature	As per figure 40 The temperature gradient must be selected in such a way that no condensation occurs on the DUT.
Test humidity	93% relative humidity
Test duration	As specified in the Performance Specification as per section F.1 „Lawson model“ The respective ramp times between 65 °C and $T_{op,max}$ are not counted towards the test duration.
Interval time t_1	47 h
Interval time t_2	1 h
Number of DUTs	6

If a coolant circuit is present, the coolant temperature must track the respective test temperature up to the limit $T_{cool,max}$. Only the ambient temperature is varied above the coolant temperature limit.



Legend

- 1 Operation_{max}
- 2 Parking_{min}

Figure 40 – Temperature profile for testing components with reduced performance at high temperatures above $T_{op,max}$

5.6.14.2.4 Requirement

The DUT must be fully functional before, during, and after the test and the key parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-03 parameter test (large) as per section 4.14.3.

5.6.15 K-15 Condensation test with assemblies

5.6.15.1 Purpose

This test simulates condensation on electronic assemblies in motor vehicles.

It is used to evaluate the robustness of the electronic assemblies against condensation.

5.6.15.2 Test

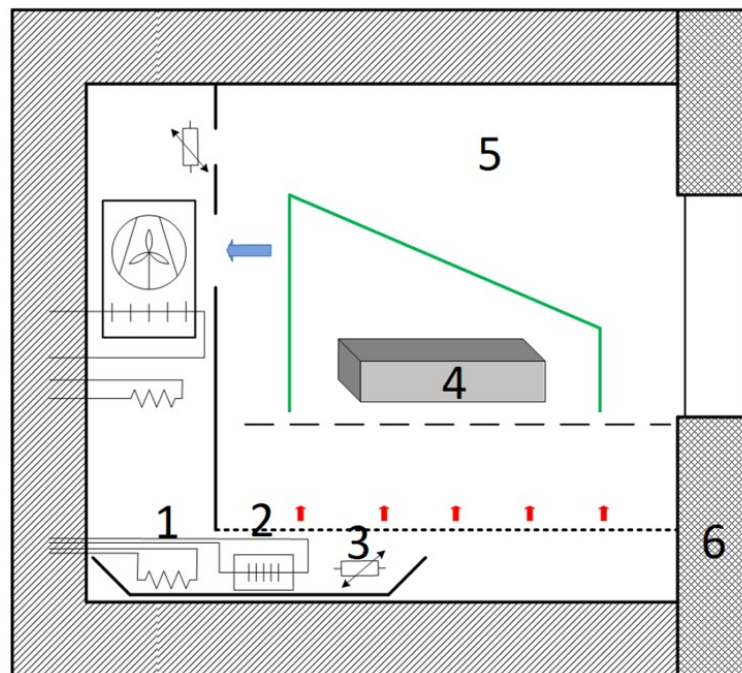
Test procedure for assemblies without a housing with parameters as per table 78:

Table 78 – Test parameters for K-15 Condensation test with assemblies

DUT operating mode	Parking _{min} P-01 parameter tests (function checks) also need to be carried out (see „test procedure“).
Testing equipment	Climatic chamber with condensation option (a specially controlled water bath is used to convert the required amount of water into water vapor) The climatic control system is switched off during the condensation phase. The test-chamber temperature is controlled by means of the temperature-controlled water bath. A suitable piece of measuring equipment must be used to record the minimum current change values in parking _{min} operating mode.
Test procedure	<ol style="list-style-type: none"> 1. The initial temperature in the climatic chamber is held for 60 min to ensure that the DUT has reached a constant temperature throughout. Then the condensation phase begins. 2. A P-01 parameter test (function check) is carried out during the condensation phase at the start of each cycle at 20 °C. The P-01 Parameter test (function check) must be carried out for max. 2 min with the lowest possible power loss. Otherwise, the DUT is heated too much and condensation is no longer possible as a result. 3. A drying phase of one hour must be carried out in the chamber after the test (5 cycles).
Test temperature	See figure 43.
Relative test chamber humidity	See figure 43 The relative test chamber humidity must be 100% (0%, -5%) during the condensation phase.
Test duration	32,5 h (5 cycles of 6,5 h each)
Test medium	Distilled water with a maximum conductivity of 5 µS/cm
DUT position	Corresponding to installation position in the vehicle Plastic brackets must be used in the climatic chamber to comply with the installation position of the assembly in the vehicle. If the assembly is used in different installation positions, the DUT must also be put in different as-installed positions in the climatic chamber.

Table 78 (continued)

Test setup	<p>See figure 41</p> <p>A plastic cover must be used during the test as per figure 42 to eliminate adverse effects in the event of different air speeds. The hood must be oriented in such a way that its slope points toward the test chamber door. The dimensions of the plastic cover must be adapted to the size of the test chamber.</p> <p>The distance of the plastic cover to the wall of the test chamber is 10% of the width/depth of the test chamber, but at least 8 cm.</p> <p>An α angle of $\geq 12^\circ$ must be used for the roof pitch of the plastic cover as per DIN EN ISO 6270-2.</p>
Test condition	<p>The condensation test must initially be carried out prior to making a final determination as to the switching layout (hardware freeze), but as early as on assemblies that have been manufactured under close-to-production conditions to optimize any condensation sensitivities that may have been determined (e.g., by changing the layout and the switching).</p> <p>If there are any changes in assembly manufacturing (e.g., circuit carrier, solder, flux, soldering process, layout, relocation of assembly line, or subcomponents), the test must be carried out again.</p>
Number of cycles	5
Number of DUTs	6 assemblies



Legend

- 1 Heating system
- 2 Heat exchanger (cooler)
- 3 Temperature sensor/controller
- 4 DUT
- 5 Test chamber
- 6 Test chamber door

Figure 41 – Test setup for K-15 Condensation test with assemblies

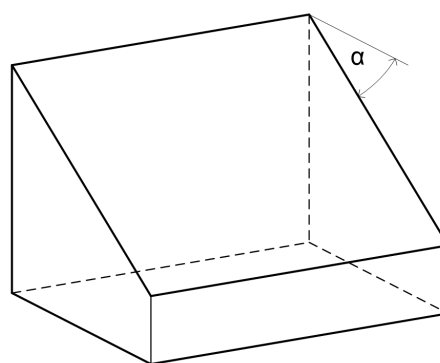
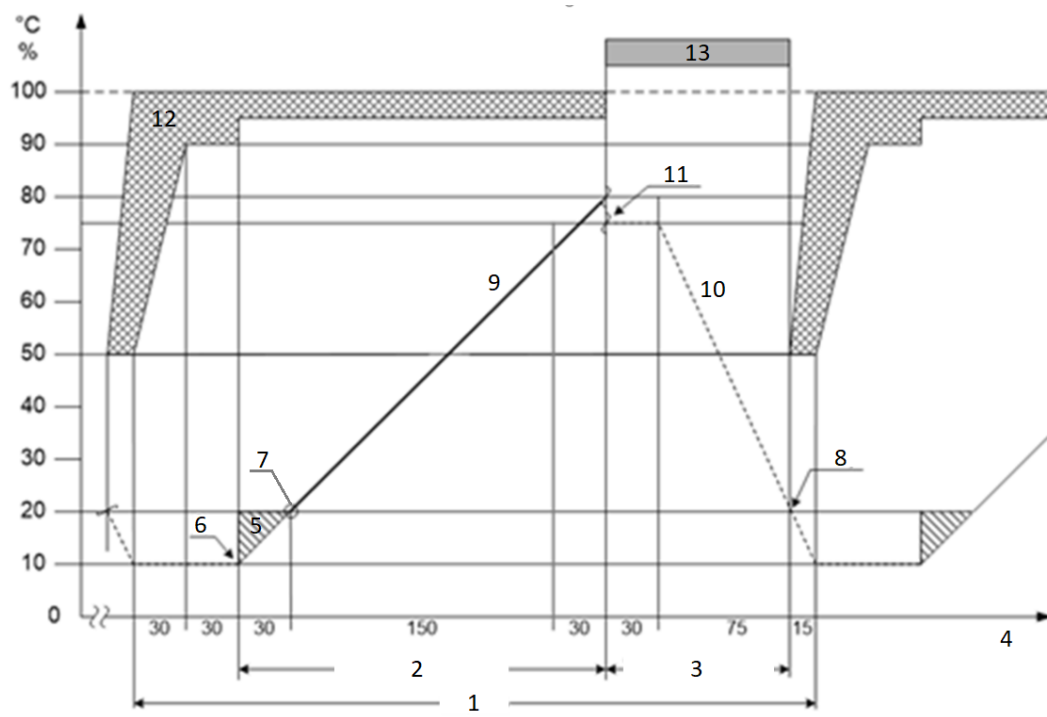


Figure 42 – Plastic cover



Legend

- 1 1 cycle
- 2 Condensation phase (The humidity and temperature of the test chamber are recorded; the temperature difference between water bath and climatic chamber must not exceed 15 K. If the temperature difference exceeds 10 K, the climate chamber heating may be temporarily switched on.)
- 3 Drying phase
- 4 Time (t) in min
- 5 Water bath temperature < 20 °C
- 6 Switch from climatic control to water bath control
- 7 Parameter test (function check) at V_{op}
- 8 The DUT must be dry ($H_{rel} < 50\%$). In order to be sure that $H_{rel} < 50\%$ is reached, the chamber humidity may be set to $H_{rel} < 30\%$.
- 9 Water bath temperature ± 1 K
- 10 Test room temperature ± 3 K
- 11 Start of the drying phase after reaching an air temperature of 75 °C
- 12 Test-chamber humidity
- 13 Humidity curve not defined

Figure 43 – Sequence for K-15 Condensation test with assemblies

See table 79.

Table 79 – Test sequence for test K-15 Condensation test with assemblies

t in min	T (climatic chamber) in °C	Relative humidity in %	T (water bath) in °C	Climatic chamber control	Water bath control	Note
Start	10	50	–	Yes	No	Preconditioning
+30	10	to 90	–	Yes	No	Humidity control via the climatic chamber
+30	10	90	–	Yes	No	Conditions in climatic chamber remain constant
+30	–	–	from 10 to 20	No	Yes	Fill the water bath, climatic chamber control system off Carry out P-01 parameter test (function check) at 20 °C
150	–	–	from 20 to 70	No	Yes	Water bath control, climatic chamber control system off
+30	–	–	To 80	No	Yes	
+30	75	–	–	Yes	No	Empty water bath
+75	20	–	–	Yes	No	Drying phase, water bath is empty
+15	10	50	–	Yes	No	

5.6.15.3 Requirement

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-03 parameter test (large) as per section 4.14.3.

In addition, the assembly must be examined for electrochemical migration (e.g., silver and tin drift) and dendrite growth.

Electrochemical migration and dendrite growth are not permissible.

Other changes to the assembly (e.g., corrosion, contamination) must be documented in the test report and evaluated together with the purchaser.

The following documentation must be enclosed with the test report:

1. Programming of the test chamber
2. Parameters (target/actual) of a cycle
3. Parameters (target/actual) of all five cycles

5.6.16 K-16 Thermal shock (without housing)

5.6.16.1 Purpose

This technology test is used to detect weak points in connections on assemblies such as solder joints.

The test must only be carried out with the component assembly without housing and mechanical parts. The required brackets must be designed in such a way that additional mechanical stresses cannot affect the assembly.

5.6.16.2 Test

Test procedure as per DIN EN 60068-2-14, Na Test with parameters as per table 80:

Table 80 – Test parameters for K-16 Thermal shock (without housing)

DUT operating mode	I.a
Minimum temperature	T_{\min}
Maximum temperature	T_{\max}
Hold time at maximum and minimum temperature	15 min after having reached a constant temperature throughout (see section 4.6)
Transfer time	≤ 10 s
Number of cycles	$\Delta T_{\text{field}} < 46$ K: 600 $\Delta T_{\text{field}} \geq 46$ K: 1 000
Number of DUTs	8 assemblies

After 300 cycles, two assemblies must be removed from the test and analyzed.

5.6.16.3 Requirement

The DUT must be fully functional before and after the test, and all parameters must meet the specifications. Proof of this must be provided by a P-03 parameter test (large) as per section 4.14.3.

300 cycles: Cracks in soldered connections are not permitted.

600 & 1 000 cycles: Cracks in soldered connections with a cumulative total length > 50% are not permitted.

5.6.17 K-17 Solar radiation

5.6.17.1 Purpose

This test simulates the influence of solar radiation and ultraviolet (UV) light on the component.

It is used to verify the resistance of the component to damage caused by material fatigue, such as cracks or discolorations.

5.6.17.2 Test

Test procedure as per DIN 75220 with parameters as per table 81:

Table 81 – Test parameters for K-17 Solar radiation

DUT operating mode	I.a
Test profiles used	The test profiles in DIN 75220 are applied, depending on the installation area of the component.
Components in the vehicle exterior	Test as per DIN 75220-Z-OUT
Components in the vehicle interior that are subject to direct solar radiation	Test as per DIN 75220-Z-IN1
Components in the vehicle interior that are subject to indirect solar radiation	Test as per DIN 75220-Z-IN2
Test duration	25 days (15 days dry, 10 days humid)
Number of cycles	1
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.

5.6.17.3 Requirement

The DUT must be fully functional before and after the test, and all parameters must meet the specifications. Proof of this must be provided by a P-03 parameter test (large) as per section 4.14.3.

The DUT must also undergo a visual inspection. Changes or damage must be documented in the test report and evaluated together with the purchaser.

5.6.18 K-18 Harmful gas test

5.6.18.1 Purpose

This test simulates the influence of harmful gases on the component, primarily on its pin contacts and switches.

It is used to verify the resistance of the component to flaw patterns such as corrosion and component damage.

5.6.18.2 Test

Test procedure as per DIN EN 60068-2-60, Method 4 with parameters as per table 82:

**Table 82 – Test parameters for K-18
Harmful gas test**

DUT operating mode	I.b	
Temperature	T _{RT}	
Humidity	75% relative humidity	
Harmful gas concentration	SO ₂	0,2 ppm
	H ₂ S	0,01 ppm
	NO ₂	0,2 ppm
	Cl ₂	0,01 ppm
Test duration	21 days	
Number of DUTs	6	

5.6.18.3 Requirement

The DUT must be fully functional before and after the test, and all parameters must meet the specifications. Proof of this must be provided by a P-03 parameter test (large) as per section 4.14.3.

In addition, the contact resistances of switches and contacts must be measured. The measured values must be within the specifications.

5.6.19 K-19 Climate test for components with watertight housings

5.6.19.1 Purpose

This test simulates the load on the component due to damp heat during the vehicle service life in the form of an accelerated test, taking into account the protective effect of watertight housings.

It is used to verify the quality and reliability of the component in terms of resistance against flaw patterns caused by damp heat, e.g., corrosion, swelling, and degradation of plastics, sealing and potting compounds.

5.6.19.2 Test

The test must be carried out with complete components (unit, electronic control unit, mechatronics, etc. with housing).

The test must be carried out as a sequence of five test blocks in the following order:

Test block 1	Damp heat, constant - severity 2
Test block 2	Damp heat, cyclic (with frost)
Test block 3	Damp heat, constant - severity 2
Test block 4	Damp heat, cyclic (with frost)
Test block 5	Damp heat, constant - severity 2

Test blocks 1, 3, and 5:

Test procedure as per DIN EN 60068-2-78 with parameters as per table 83:

Table 83 – Test parameters for K-19 Climate test for components with watertight housings - Test blocks 1, 3, and 5

Operating mode of the DUT	Parking_{min} A P-01 parameter test (function check) must be carried out 12 hours after the start of the test block, and every 24 hours thereafter.
Test duration per test block	The total test duration (test blocks 1 to 5) corresponds to the test duration of test K-14 b, Damp heat, constant – severity 2. Of this, a test duration of 240 hours each is allotted to test blocks 2 and 4. The remaining test duration is allotted in thirds to test blocks 1, 3, and 5: $\text{Test duration}_{\text{test block 1}} = \text{Test duration}_{\text{test block 3}} = \text{Test duration}_{\text{test block 5}} = 1/3 (\text{total test duration} - 2 \times 240 \text{ hours}).$
Test temperature and test humidity	The same as for the tests in K-14 b Damp heat, constant - severity 2
Number of DUTs	6

If a coolant circuit is present, the coolant temperature must track the respective test temperature up to the limit $T_{\text{cool,max}}$. Only the ambient temperature is varied above the coolant temperature limit.

Test blocks 2 and 4:

Procedure as per test K-09 Damp heat, cyclic (with frost), section 5.6.9.2 „Test“

5.6.19.3 Requirement

The DUT must be fully functional before, during, and after the test, and all parameters must be within the specifications. Proof of this must be provided by continuous parameter monitoring and a P-03 parameter test (large) as per section 4.14.3.

5.7 Chemical requirements and tests

5.7.1 C-01 Chemical tests

5.7.1.1 Purpose

This test simulates the temporal load on the component when exposed to various chemicals.

It is used to verify the resistance of the component against chemical changes on the housing and functional impairment due to chemical reactions.

5.7.1.2 Test

See table 84

Table 84 – Test parameters for chemical tests

DUT operating mode	As defined in the Performance Specification
Chemicals	The chemicals to be applied must be agreed upon with the purchaser. Typical chemicals are specified in ISO 16750-5.
Conditioning	Unless otherwise specified, the DUT and the chemicals must be aged in a standard atmosphere.
Test procedure	<p>The test must be carried out as per ISO 16750-5:</p> <ol style="list-style-type: none"> 1. The chemical must be applied to the DUT at T_{RT}. A suitable application method must be selected for each chemical. The selected application method must be documented in the test report. It must be ensured that the DUT is sufficiently covered by the chemical externally on all materials, material interfaces (e.g., seals, material transitions), and labels being used. 2. The DUT must then be aged at the temperature indicated for the specified exposure time.
Number of DUTs	<p>1 DUT per chemical</p> <p>It is possible to use the DUT multiple times for several chemicals, in consultation with the purchaser</p>

Safety instructions and warning labels for the chemicals must be adhered to.

If specified in the Performance Specification, E85 fuel must be tested as an additional chemical as per DIN EN 15293.

5.7.1.3 Requirement

The DUT must be fully functional before and after the test, and all parameters must meet the specifications. Proof of this must be provided by a P-03 parameter test (large) as per section 4.14.3.

Changes to lettering and markings must be documented in the test report and agreed upon with the purchaser.

5.8 Service life tests

5.8.1 L-01 Service life test – Mechanical/hydraulic durability testing

5.8.1.1 Purpose

This test simulates the function/actuation cycles of the **component** during the vehicle service life. It is used to verify the quality and reliability of the **component** with respect function/actuation cycles such as brake actuations, seat adjustment cycles and switch/button actuations.

5.8.1.2 Test

Test details must be defined according to the function/actuation cycle in the Performance Specification.

See **table 85**

Table 85 – Test parameters for L-01 Service life test - mechanical/hydraulic durability testing

DUT operating mode	Operation _{max} in accordance with the function/actuation cycle
Test temperature	The function/actuation cycles must be carried out at the temperatures specified in the temperature load spectrum, the duration of which depends on their percentage share (see appendix C). At least two temperature ramps must be cycled through in the process as per appendix C .
Number of function/actuation cycles	As defined in the Performance Specification
Number of DUTs	6

When performing the test, the installation position of the **component** in the vehicle must be recreated.

If a coolant circuit is present, the coolant temperature must track the respective test temperature to the limits $T_{cool,min}$ and $T_{cool,max}$. Only the ambient temperature is varied outside of the coolant temperature limits.

5.8.1.3 Requirement

The DUT must be fully functional before, during, and after the test and all key parameters must be within the specifications. This must be verified by continuous parameter monitoring. Intermediate measurements at 25%, 50%, and 75% of the test duration and parameter tests as per the test sequence plan must only be carried out if the **functions** of the **component** cannot be adequately monitored during the test.

The intermediate measurements must be carried out as a P-03 parameter test (large) as per **section 4.14.3**.

The data from continuous parameter monitoring must be evaluated with respect to drifts, trends, and irregular behavior or anomalies.

For components on coolant circuits:

In the case of components with coated copper parts in the coolant path, these copper parts must be examined with a stereo microscope at 20x magnification after the test. Flaws or copper corrosion perceptible during this examination are not permissible.

5.8.2 L-02 Service life test - high-temperature durability testing

5.8.2.1 Purpose

This test simulates the thermal load on the component during electrical operation over the vehicle service life in the form of an accelerated test.

It is used to verify the quality and reliability of the component with respect to thermally induced flaw patterns such as diffusion and oxidation.

5.8.2.2 Test

5.8.2.2.1 Test for components without a connection to the coolant circuit, without reduced performance at high temperatures

Test procedure as per DIN EN 60068-2-2 with parameters as per table 86:

Table 86 – Test parameters for L-02 Service life test - high-temperature durability testing - test for components without a connection to the coolant circuit, without reduced performance at high temperatures

DUT operating mode	Intermittently 47 h operation _{max} and 1 h parking _{min} In the operation _{max} operating mode, the component must be operated intermittently in all relevant operating modes with a high operating load. The ratio of time shares between these operating modes must correspond to the ratio of the respective partial test durations.
Test duration	The respective partial test duration must be calculated as per section D.2 (Arrhenius model) for each relevant operating situation as per section 4.10. The total test duration is the sum of all partial test durations.
Test temperature	T _{max}
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.

5.8.2.2.2 Test for components without a connection to the coolant circuit, with reduced performance at high temperatures

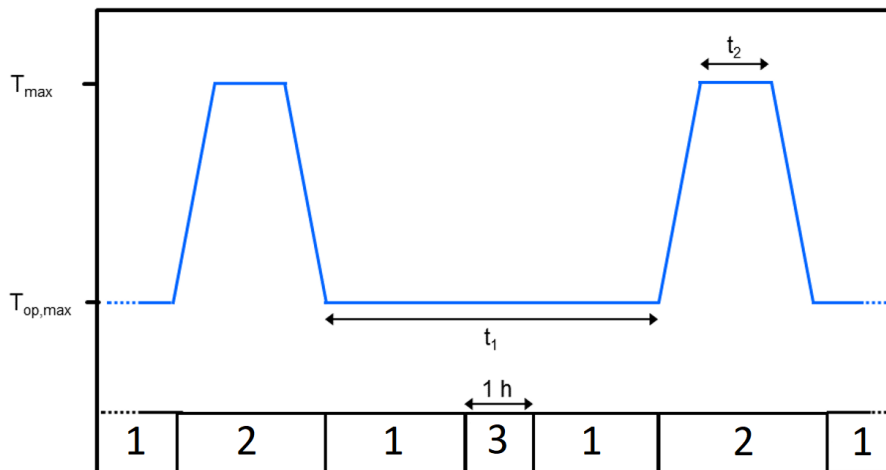
For components with reduced performance (e.g., reduction of LCD backlighting) in the event of high temperatures at or above T_{op,max}, the test as per table 86 must not be carried out at a constant temperature of T_{max}, but rather with a temperature profile with the following parameters:

Test procedure as per DIN EN 60068-2-2 with parameters as per table 87:

Table 87 – Test parameters for L-02 Service life test - high-temperature durability testing - test for components without a connection to the coolant circuit, with reduced performance at high temperatures

DUT operating mode	Intermittently as per figure 44 The component must be operated intermittently in all relevant operating modes at a high operating load in the operation _{max} operating mode and operation _{max} ^{a)} operating mode. The ratio of time shares between these operating modes must correspond to the ratio of the respective partial test durations.
Test duration	The respective partial test duration must be calculated as per section D.2 (Arrhenius model) for each relevant operating situation as per section 4.10. The total test duration is the sum of all partial test durations. The relevant ramp times between T_{\max} and $T_{\text{op,max}}$ are not counted towards the test duration.
Test temperature	See figure 44.
Interval time t_1	To be calculated as per section D.4
Interval time t_2	To be calculated as per section D.4
Number of DUTs	6
a) A reduction in performance is permitted for $T > T_{\text{op,max}}$.	

When performing the test, the installation position of the component in the vehicle must be recreated.



Legend

- 1 Operation_{max}
- 2 Operation_{max}^{a)}
- 3 Parking_{min}^{b)}

a) A reduction in performance is permitted for $T > T_{\text{op,max}}$.

b) The 1 h of Parking_{min} is applied at $T_{\text{op,max}}$.

Figure 44 – Temperature profile for testing components with reduced performance at high temperatures

5.8.2.2.3 Test for components with a connection to a coolant circuit

Test procedure as per DIN EN 60068-2-2 with parameters as per table 88:

Table 88 – Test parameters for L-02 Service life test - high-temperature durability testing - test for components with a connection to a coolant circuit

DUT operating mode	Intermittently 47 h operation _{max} and 1 h parking _{min} In the operation _{max} operating mode, the component must be operated intermittently in all relevant operating modes with a high operating load. The ratio of time shares between these operating modes must correspond to the ratio of the respective partial test durations.
Test duration	The respective partial test duration must be calculated as per section D.6 (Arrhenius model) for each relevant operating situation as per section 4.10. The total test duration is the sum of all partial test durations.
Test temperature (ambient)	As per section D.6 (Arrhenius model to be used for components on coolant circuits)
Test temperature (coolant)	As per section D.6 (Arrhenius model to be used for components on coolant circuits)
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.

5.8.2.3 Requirement

The DUT must be fully functional before, during, and after the test and all key parameters must be within the specifications. This must be verified by continuous parameter monitoring. Intermediate measurements at 25%, 50%, and 75% of the test duration and parameter tests as per the test sequence plan must only be carried out if the functions of the component cannot be adequately monitored during the test.

The intermediate measurements must be carried out as a P-03 parameter test (large) as per section 4.14.3.

The data from continuous parameter monitoring must be evaluated with respect to drifts, trends, and irregular behavior or anomalies.

For components on coolant circuits:

In the case of components with coated copper parts in the coolant path, these copper parts must be examined with a stereo microscope at 20x magnification after the test. Flaws or copper corrosion perceptible during this examination are not permissible.

5.8.3 L-03 Service life test – Temperature cycle durability testing

5.8.3.1 Purpose

This test simulates the thermomechanical load on the component due to temperature changes during the vehicle service life in the form of an accelerated test.

It is used to verify the quality and reliability of the component with respect to thermomechanically induced flaw patterns such as aging and cracking in solder joints, adhesive joints, bonded joints, and welded joints, as well as on seals and housings.

5.8.3.2 Test

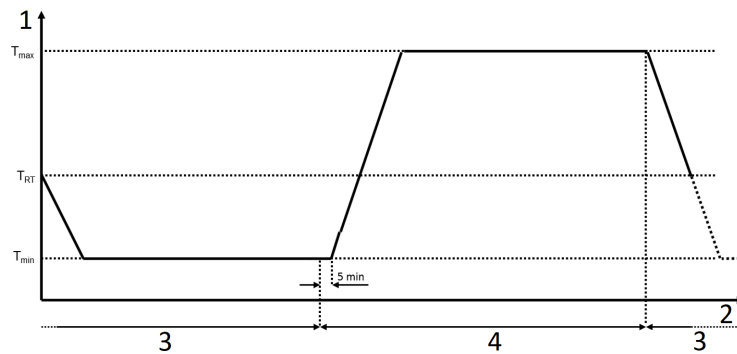
5.8.3.2.1 Test for components without a connection to the coolant circuit, without reduced performance at low or high temperatures

Test procedure as per DIN EN 60068-2-14 with parameters as per table 89:

Table 89 – Test parameters for L-03 Service life test - temperature cycle durability testing - test for components without a connection to the coolant circuit, without reduced performance at low or high temperatures

DUT operating mode	Intermittently, operation _{max} and parking _{min} as per figure 45
Temperature profile	As per figure 45
Minimum test temperature	T _{min}
Maximum test temperature	T _{max}
Temperature gradient	4 K/min
Hold times at T _{min} and T _{max}	15 min after having reached a constant temperature throughout (see section 4.6)
Number of cycles	The total number of test cycles must be calculated as per section E.2 (Coffin-Manson model), while taking all relevant operating situations into account (see section 4.10).
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.



Legend

- 1 Temperature
- 2 Time
- 3 $Parking_{min}$
- 4 $Operation_{max}$

Figure 45 – Test profile for L-03 Service life test - temperature cycle durability testing for components without reduced performance at low or high temperatures

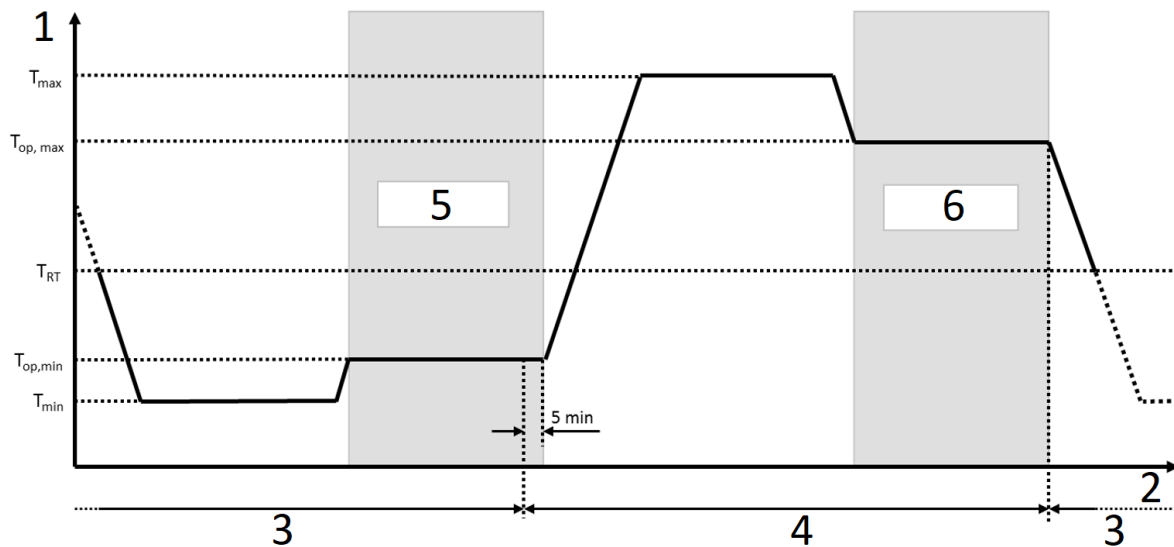
5.8.3.2.2 Test for components without a connection to the coolant circuit, with reduced performance at low or high temperatures

For components with reduced performance (e.g., reduction of LCD backlighting) at low or high temperatures, less than $T_{op,min}$ or greater than $T_{op,max}$, the test must be carried out with parameters as per table 90:

Table 90 – Test parameters for L-03 Service life test - temperature cycle durability testing - test for components without a connection to the coolant circuit, with reduced performance at low or high temperatures

DUT operating mode	Intermittently, $Parking_{min}$ and $Operation_{max}$ as per figure 46
Temperature profile	As per figure 46
Minimum test temperature	T_{min}
Maximum test temperature	T_{max}
Temperature gradient	4 K/min
Hold times at T_{min} , T_{max} , $T_{op,min}$ and $T_{op,max}$	15 min after having reached a constant temperature throughout (see section 4.6)
Number of cycles	The total number of test cycles must be calculated as per section E.2 (Coffin-Manson model), while taking all relevant operating situations into account (see section 4.10).
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.



Legend

- 1 Temperature
- 2 Time
- 3 $T_{\text{parking, min}}$
- 4 $T_{\text{operation, max}}$
- 5 Only required if $T_{\text{op, min}} > T_{\text{min}}$
- 6 Only required if $T_{\text{op, max}} < T_{\text{max}}$

Figure 46 – Temperature profile - test for components with reduced performance at low or high temperatures

5.8.3.2.3 Test for components on the coolant circuit

For components on coolant circuits, the test must be carried out with parameters as per table 91:

Table 91 – Test parameters for L-03 Service life test - temperature cycle durability testing - test for components on the coolant circuit

DUT operating mode	Intermittently, parking _{min} and operation _{max} as per figure 45 or figure 46
Temperature profile	As per figure 45 or figure 46
Minimum test temperature	T_{min} and $T_{\text{cool, min}}$
Maximum test temperature	T_{max} and $T_{\text{cool, max}}$
Temperature gradient	4 K/min
Hold times at T_{min} , T_{max} , $T_{\text{op, min}}$ and $T_{\text{op, max}}$	15 min after having reached a constant temperature throughout (see section 4.6)
Number of cycles	The total number of test cycles must be calculated as per section E.4 (Coffin-Manson model for use with components on coolant circuits), while taking all relevant operating situations into account (see section 4.10).
Number of DUTs	6

When performing the test, the installation position of the component in the vehicle must be recreated.

5.8.3.3 Requirement

The DUT must be fully functional before, during, and after the test and all key parameters must be within the specifications. This must be verified by continuous parameter monitoring. Intermediate measurements at 25%, 50%, and 75% of the test duration and parameter tests as per the test sequence plan must only be carried out if the functions of the component cannot be adequately monitored during the test.

The intermediate measurements must be carried out as a P-03 parameter test (large) as per section 4.14.3.

The data from continuous parameter monitoring must be evaluated with respect to drifts, trends, and irregular behavior or anomalies.

For components on coolant circuits:

In the case of components with coated copper parts in the coolant path, these copper parts must be examined with a stereo microscope at 20x magnification after the test. Flaws or copper corrosion perceptible during this examination are not permissible.

6 Applicable documents

The following documents cited in the standard are required for the application of this standard:

Some of the cited documents are translations from the German original. The translations of German terms in such documents may differ from those used in this standard, resulting in terminological inconsistency.

Standards whose titles are given in German may be available only in German. Editions in other languages may be available from the institution issuing the standard.

VW 80005	Electrical and Electronic Units in Motor Vehicles up to 3,5 t; Analysis Requirements
DIN 75220	Ageing of automotive components in solar simulation units
DIN EN 13018	Non-destructive testing - Visual testing - General principles
DIN EN 15293	Automotive fuels - Automotive ethanol (E85) fuel - Requirements and test methods
DIN EN 60068-2-1	Environmental testing - Part 2-1: Tests - Test A: Cold
DIN EN 60068-2-14	Environmental testing - Part 2-14: Tests - Test N: Change of temperature
DIN EN 60068-2-2	Environmental testing - Part 2-2: Tests - Test B: Dry heat
DIN EN 60068-2-27	Environmental testing - Part 2-27: Tests - Test Ea and guidance: Shock
DIN EN 60068-2-30	Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle)
DIN EN 60068-2-38	Environmental Testing - Part 2-38: Tests - Test Z/AD: Composite Temperature/Humidity Cyclic Test (IEC 60068-2-38:2009); German Version EN 60068-2-38:2009
DIN EN 60068-2-6	Environmental testing - Part 2-6: Tests - Test Fc: Vibration (sinusoidal)
DIN EN 60068-2-60	Environmental testing - Part 2-60: Tests - Test Ke: Flowing mixed gas corrosion test
DIN EN 60068-2-64	Environmental testing - Part 2-64: Tests - Test Fh: Vibration, broadband random and guidance
DIN EN 60068-2-78	Environmental testing - Part 2-78: Tests - Test Cab: Damp heat, steady state
DIN EN IEC 60068-2-11	Environmental testing - Part 2-11: Tests - Test Ka: Salt mist
DIN EN ISO/IEC 17025	General requirements for the competence of testing and calibration laboratories
DIN EN ISO 11124-2	Preparation of steel substrates before application of paints and related products - Specifications for metallic blast-cleaning abrasives - Part 2: Chilled-iron grit
DIN EN ISO 20567-1	Paints and varnishes - Determination of stone-chip resistance of coatings - Part 1: Multi-impact testing
DIN EN ISO 6270-2	Paints and varnishes - Determination of resistance to humidity - Part 2: Condensation (in-cabinet exposure with heated water reservoir)

ISO 12103-1	Road vehicles - Test contaminants for filter evaluation - Part 1: Arizona test dust
ISO 16750-3	Road vehicles - Environmental conditions and testing for electrical and electronic equipment - Part 3: Mechanical loads
ISO 16750-5	Road vehicles - Environmental conditions and testing for electrical and electronic equipment - Part 5: Chemical loads
ISO 20653	Road vehicles - Degrees of protection (IP code) - Protection of electrical equipment against foreign objects, water and access
ISO 26262-1	Road vehicles - Functional safety - Part 1: Vocabulary
ISO 26262-10	Road vehicles - Functional safety - Part 10: Guidelines on ISO 26262
ISO 26262-11	Road vehicles - Functional safety - Part 11: Guidelines on application of ISO 26262 to semiconductors
ISO 26262-12	Road vehicles - Functional safety - Part 12: Adaptation of ISO 26262 for motorcycles
ISO 26262-2	Road vehicles - Functional safety - Part 2: Management of functional safety
ISO 26262-3	Road vehicles - Functional safety - Part 3: Concept phase
ISO 26262-4	Road vehicles - Functional safety - Part 4: Product development at the system level
ISO 26262-5	Road vehicles - Functional safety - Part 5: Product development at the hardware level
ISO 26262-6	Road vehicles - Functional safety - Part 6: Product development at the software level
ISO 26262-7	Road vehicles - Functional safety - Part 7: Production, operation, service and decommissioning
ISO 26262-8	Road vehicles - Functional safety - Part 8: Supporting processes
ISO 26262-9	Road vehicles - Functional safety - Part 9: Automotive safety integrity level (ASIL)-oriented and safety-oriented analyses

Appendix A (normative) Test sequence

A.1 Test sequence plan

The tests that are not required as per the test selection tables must be removed from the test sequence plan.

All components are tested with new, original contact systems. Original connectors/cables must be connected to the DUT before the start of the testing. Tests in operating mode I.a are excluded from this. The wiring harness used with the contact system must be designed in such a way that the wiring harness extends out of the test chamber without any additional intermediate connections.

A sample part must be provided for the purchaser as a reference for each test sequence at the beginning of the validation.

A.2 Test group I - electrical tests

Any order, or in parallel

Number of DUTs for the test sequence plan as per figure A.1: 6 each

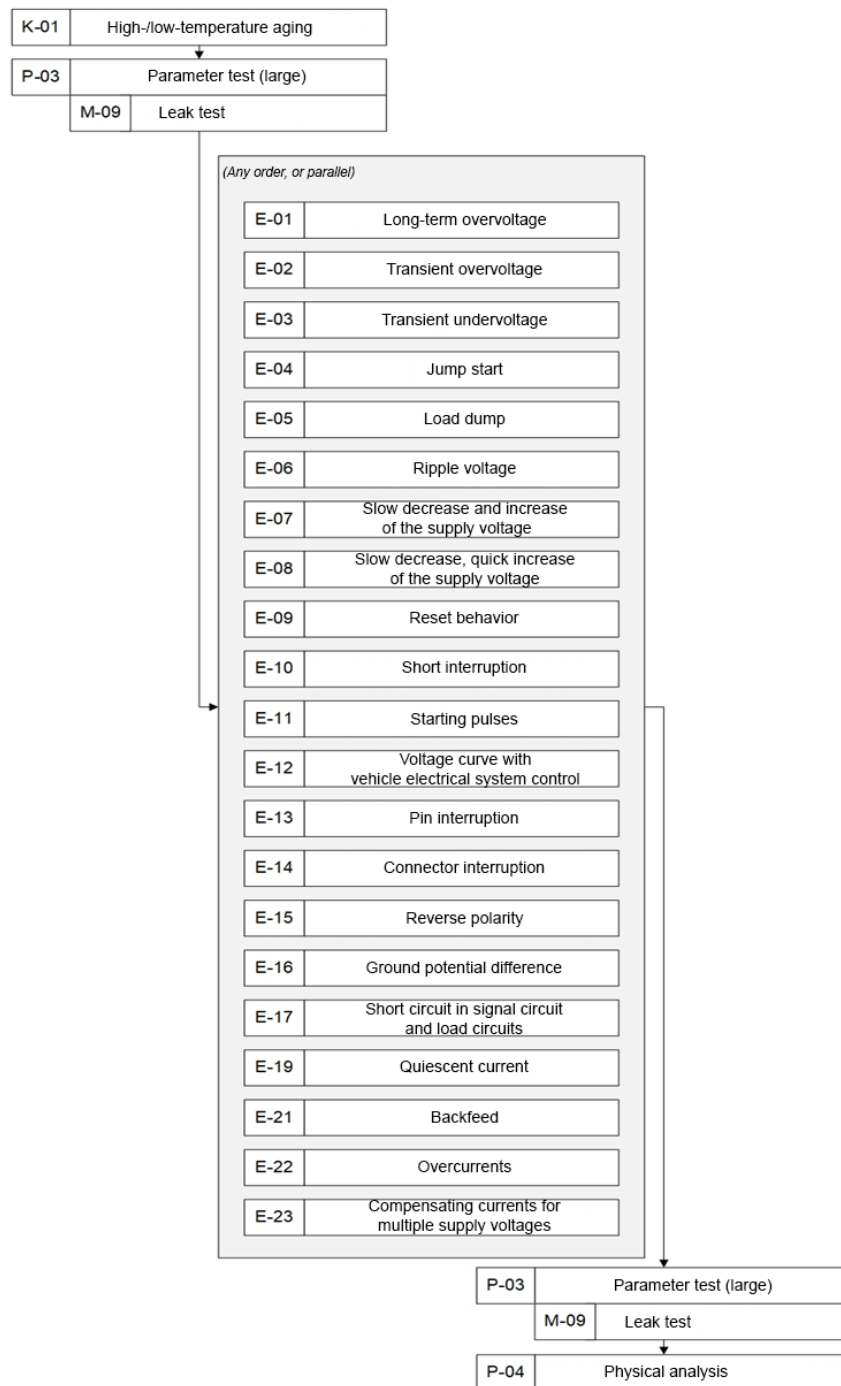


Figure A.1 – Test group I - test sequence plan for electrical tests

A.3 Test group II - tests

Any order, or in parallel

Number of DUTs for the test sequence plan as per figure A.2: 6 each

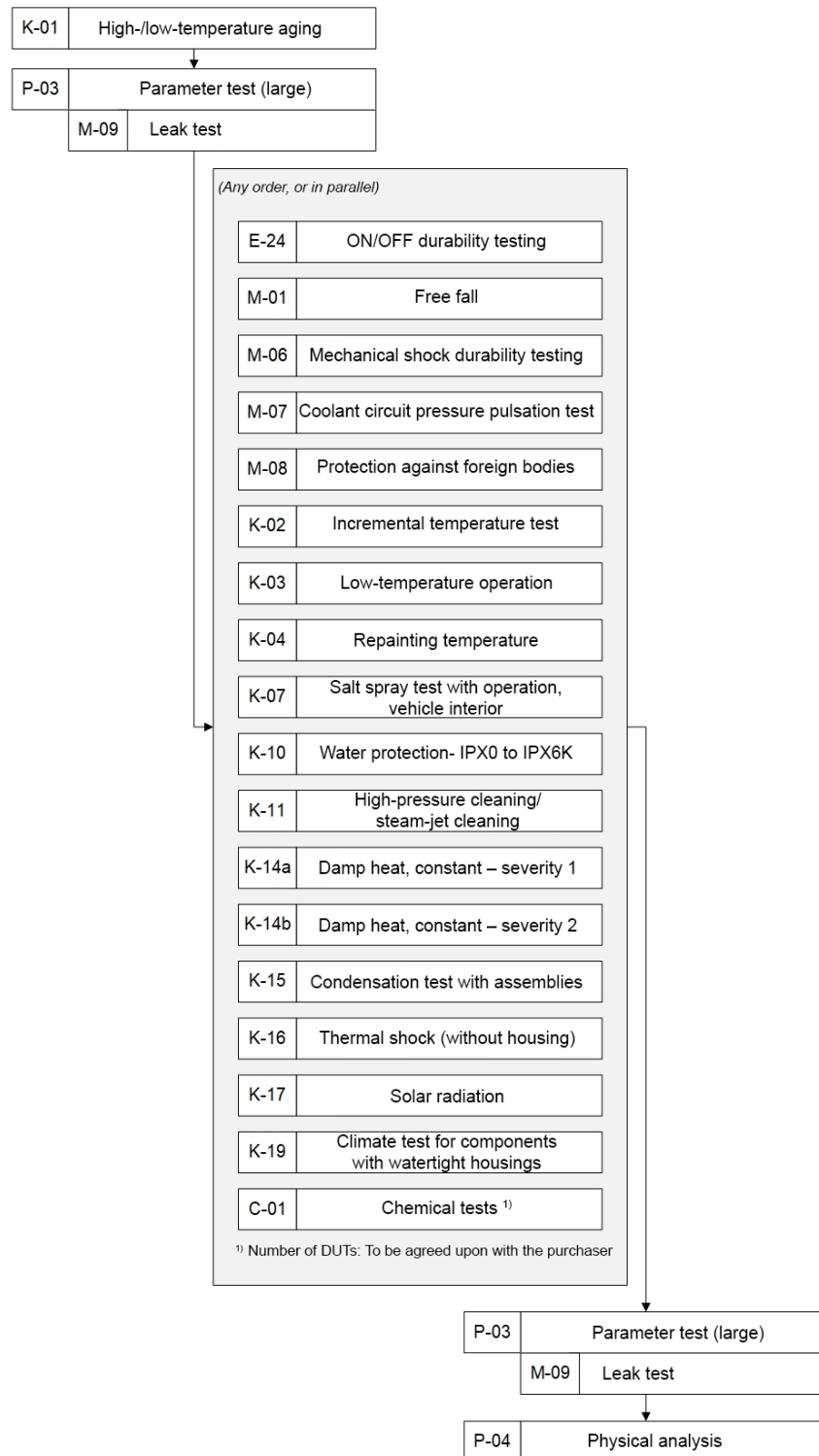


Figure A.2 – Test group II - test sequence plan

A.4 Test group III - environmental tests

Fixed order for components with protection class > IPX3; any order, or in parallel for other components

Number of DUTs for the test sequence plan as per figure A.3: 6

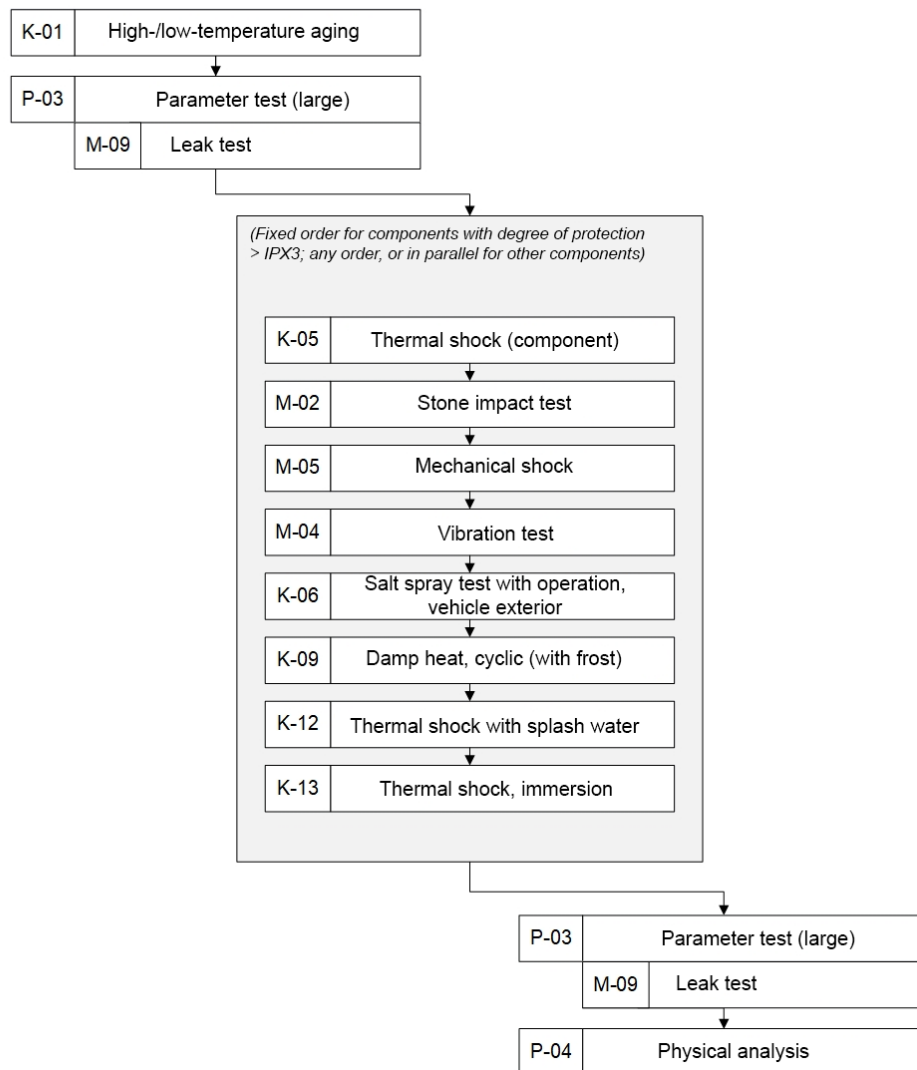


Figure A.3 – Test group III - test sequence plan for environmental tests

A.5 Test group IV - service life tests

Carried out in parallel

Number of DUTs for the test sequence plan as per figure A.4: 6 each

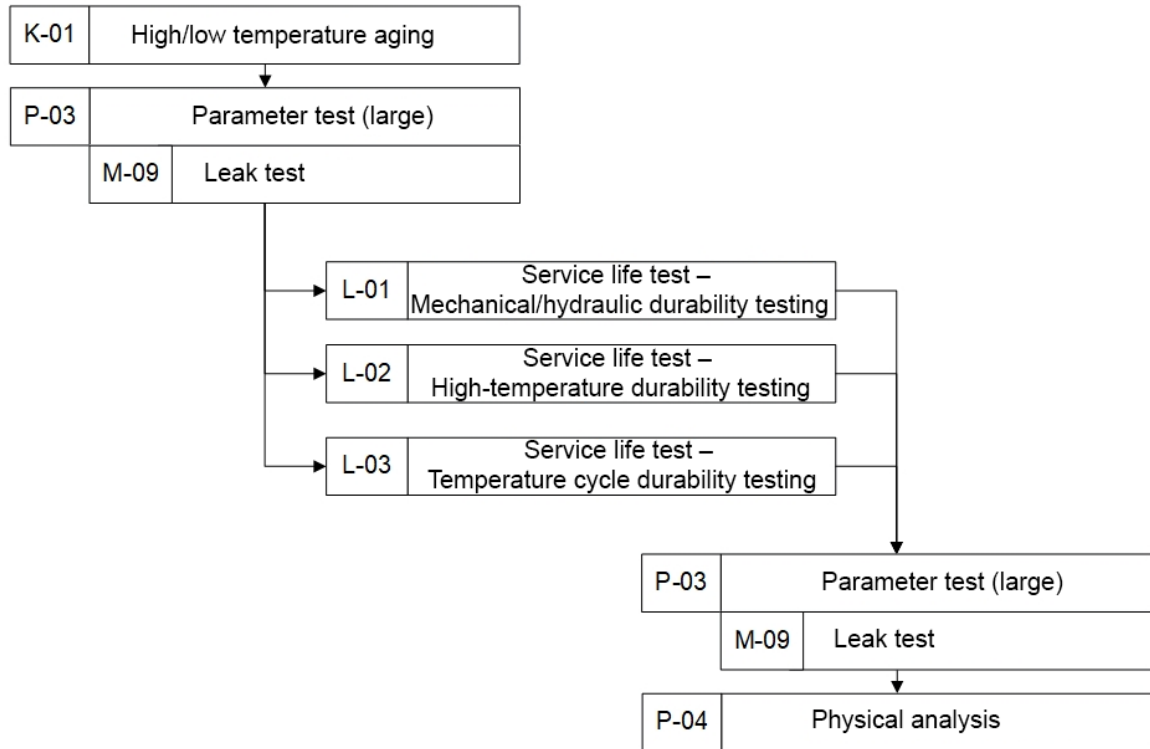


Figure A.4 – Test group IV - test sequence plan for service life testing

A.6 **Test group V - tests**

Fixed order

High/low temperature aging and a parameter test (large) do not need to be carried out before this test group.

NOTE A.1: These tests are not carried out in this test group so as not to influence the test results of the humidity tests (e.g., by vaporizing residues from the manufacturing process).

Number of DUTs for the test sequence plan as per figure A.5: 6

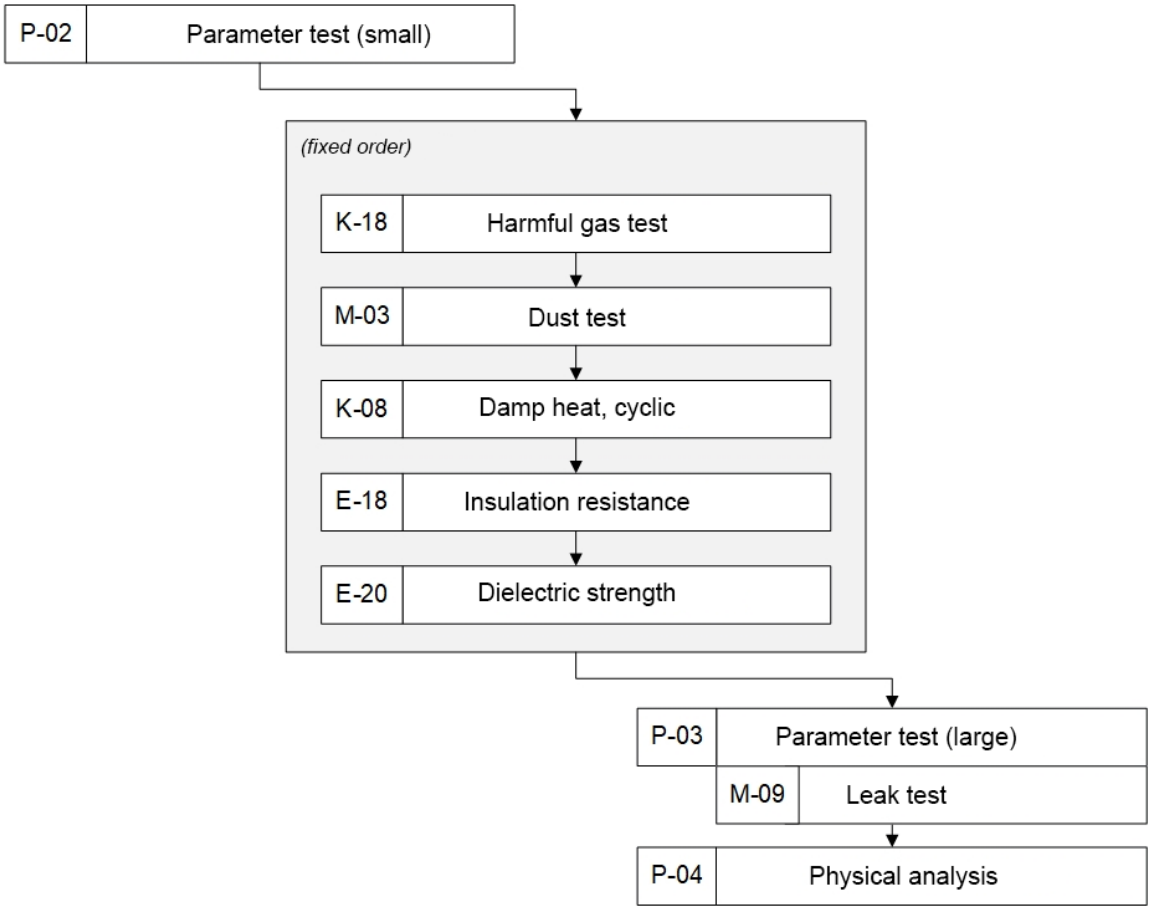


Figure A.5 – Test group V - test sequence plan (fixed order)

Appendix B (normative) Typical temperature load spectra for various installation areas

B.1 Overview of installation areas

See table B.1.

Table B.1 – Overview of installation areas, typical spectra and temperature rises

Installation area of the component	Load spectrum no.	Temperature rise in K
Vehicle interior, without special requirement	1	36
Body-mounted, without special requirements	1	36
Vehicle interior, exposed to solar radiation	2	46
Body-mounted, roof	2	46
Engine compartment, but not on the engine	3	55
On the radiator	3	55
Engine-mounted	4	70
Transmission-mounted	4	70

B.2 Temperature load spectrum 1

See table B.2.

Table B.2

Temperature in °C	Distribution in %
-40	2
10	8
23	14
40	60
65	9
75	6
80	1

B.3 Temperature load spectrum 2

See table B.3.

Table B.3

Temperature in °C	Distribution in %
-40	2
10	8
23	14
45	55
70	12
90	8
105	1

B.4 Temperature load spectrum 3

See table B.4.

Table B.4

Temperature in °C	Distribution in %
-40	2
10	8
23	14
55	50
85	18
105	7
120	1

B.5 Temperature load spectrum 4

See table B.5.

Table B.5

Temperature in °C	Distribution in %
-40	2
10	8
23	14
80	55
105	12
130	8
140	1

Appendix C (normative) Calculation for the "Mechanical/hydraulic durability testing" service test procedure

C.1 Calculation

The temperature load spectrum used is applied to calculate the mechanical/hydraulic function/actuation cycles to be tested.

See table C.1.

Table C.1 – Temperature load spectrum

Temperature in °C	Distribution in %
$T_{\text{field},1}$	p_1
$T_{\text{field},2}$	p_2
$T_{\text{field},3}$	p_3
...	...
$T_{\text{field},n}$	p_n

The mechanical/hydraulic function/actuation cycles to be tested are distributed to each temperature $T_{\text{field},1} \dots T_{\text{field},n}$ from the temperature load spectrum used in accordance with formula (C.1).

$$n_{T_{\text{field},n}} = n_{\text{total}} \times p_i \quad (\text{C.1})$$

The mechanical/hydraulic function/actuation cycles must be tested as per figure C.1. At least two temperature ramps must be carried out. For this purpose, formula (C.1) must be added to with formula (C.2):

$$n_{T_{\text{field},i}} = \frac{n_{\text{total}} \times p_i}{\text{Temperature ramps}} \quad (\text{C.2})$$

Legend

$n_{T_{\text{field},i}}$	Number of mechanical/hydraulic function/actuation cycles for temperature level $T_{\text{field},i}$
n_{total}	Number of mechanical/hydraulic function/actuation cycles to be tested
p_i	Percentage share of mechanical/hydraulic function/actuation cycles of the component at temperature $T_{\text{field},i}$ in the field
Temperature ramps	Number of temperature ramps; at least two temperature ramps should be carried out.

The total test duration is yielded from formula (C.3) and formula (C.4):

$$t_{\text{test}_T \text{ field},i} = n_{T_{\text{field},i}} \times t_{\text{cycle}} \quad (\text{C.3})$$

Legend

$t_{test_T_{field,i}}$	Test duration for temperature value $T_{field,i}$
t_{cycle}	Time for a mechanical/hydraulic function/actuation cycle to be tested

$$t_{test_total} = \left(t_{test_T_{field,1}} + \dots + t_{test_T_{field,n}} + \text{Duration of temperature change} \right) \times \text{Temperature ramps} \tag{C.4}$$

Legend

Duration of Duration for a temperature change between the temperature values for a temperature ramp at a temperature gradient of 2 °C/min

temperature change

If a coolant circuit is present, the coolant temperature must track the respective test temperature to the limits $T_{cool,min}$ and $T_{cool,max}$. Only the ambient temperature is varied outside of the coolant temperature limits.

C.2 Example calculation

For an electronic control unit with the temperature load spectrum indicated in [table C.2](#)

Table C.2 – Example temperature load spectrum

Temperature in °C	Distribution in %
-40	6
23	20
60	65
100	8
105	1

and

Number of function/actuation cycles: 100 000

Cycle duration t_{cycle} : 8 s/cycle

Duration of temperature change: 240 min

the test duration for the "Mechanical/hydraulic durability testing" service life test is calculated as follows:

The percentage shares of the function/actuation cycles of the component are calculated for all temperatures (see [table C.2](#)) in the temperature load spectrum specified above using [formula \(C.1\)](#).

$$n_{T_{\text{field},1}} = n_{\text{total}} \times p_1 = 100\,000 \text{ cycles} \times 0.06 = 6\,000 \text{ cycles} \quad (\text{C.5})$$

$$n_{T_{\text{field},2}} = n_{\text{total}} \times p_2 = 100\,000 \text{ cycles} \times 0.20 = 20\,000 \text{ cycles} \quad (\text{C.6})$$

$$n_{T_{\text{field},3}} = n_{\text{total}} \times p_3 = 100\,000 \text{ cycles} \times 0.65 = 65\,000 \text{ cycles} \quad (\text{C.7})$$

$$n_{T_{\text{field},4}} = n_{\text{total}} \times p_4 = 100\,000 \text{ cycles} \times 0.08 = 8\,000 \text{ cycles} \quad (\text{C.8})$$

$$n_{T_{\text{field},5}} = n_{\text{total}} \times p_5 = 100\,000 \text{ cycles} \times 0.01 = 1\,000 \text{ cycles} \quad (\text{C.9})$$

The partial test durations for the relevant temperatures are calculated using [formula \(C.3\)](#):

$$t_{\text{test}_T_{\text{field},1}} = n_{T_{\text{field},1}} \times t_{\text{Cycle}} = 6\,000 \text{ cycles} \times 8 \frac{\text{s}}{\text{Cycle}} = 48\,000 \text{ s} \quad (\text{C.10})$$

$$t_{\text{test}_T_{\text{field},2}} = n_{T_{\text{field},2}} \times t_{\text{Cycle}} = 20\,000 \text{ cycles} \times 8 \frac{\text{s}}{\text{Cycle}} = 160\,000 \text{ s} \quad (\text{C.11})$$

$$t_{\text{test_T}_{\text{field},3}} = n_{\text{T}_{\text{field},3}} \times t_{\text{Cycle}} = 65\,000 \text{ cycles} \times 8 \frac{\text{s}}{\text{Cycle}} = 520\,000 \text{ s} \quad (\text{C.12})$$

$$t_{\text{test_T}_{\text{field},4}} = n_{\text{T}_{\text{field},4}} \times t_{\text{Cycle}} = 8\,000 \text{ cycles} \times 8 \frac{\text{s}}{\text{Cycle}} = 64\,000 \text{ s} \quad (\text{C.13})$$

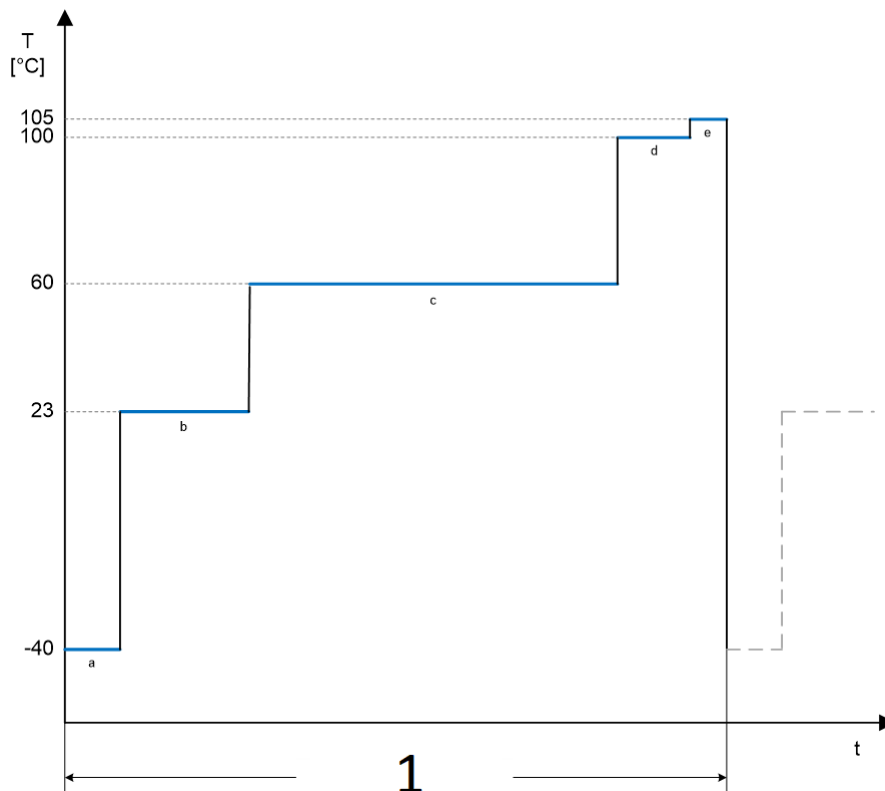
$$t_{\text{test_T}_{\text{field},5}} = n_{\text{T}_{\text{field},5}} \times t_{\text{Cycle}} = 1\,000 \text{ cycles} \times 8 \frac{\text{s}}{\text{Cycle}} = 8\,000 \text{ s} \quad (\text{C.14})$$

The total test duration for the "Mechanical/hydraulic durability testing" service life test is calculated using formula (C.4):

$$t_{\text{test_total}} = 48\,000 \text{ s} + 160\,000 \text{ s} + 520\,000 \text{ s} + 64\,000 \text{ s} + 8\,000 \text{ s} + 240 \text{ min} \times 60 \text{ s} \quad (\text{C.15})$$

$$t_{\text{test_total}} = 814\,400 \text{ s} = 13\,573 \text{ min} = 226 \text{ h} \quad (\text{C.16})$$

The total test duration for the component is $t_{\text{test,total}} = 226 \text{ h}$.



Legend

1 1 temperature ramp

Figure C.1 – Temperature curve for mechanical/hydraulic durability testing

Appendix D (normative) Calculation models for the "High-temperature durability testing" service life test

D.1 Adaptation of the test temperatures to reduce the test duration

To reduce the test duration for components that are actively operated in several operating situations, the test temperature T_{\max} (or $T_{CC,\max}$) can be increased to test individual operating situations relevant to the component. For this purpose, the absolute maximum temperature T_{\max} (or $T_{CC,\max}$) can be applied as the test temperature for the operating situations relevant to the component. The component must remain fully functional here. It must also be ensured that all parts, subcomponents and materials that are part of the component are not operated outside of their respective specification limits (temperature limits), taking into account the self-heating generated by the component depending on the required operating mode.

The test temperature can be adapted for individual or multiple operating situations that are relevant to the component. The test durations must be calculated as per section D.2 in each case.

Details concerning an increase in the test temperature and the resulting test durations must be agreed upon between the purchaser and the contractor, and documented.

D.2 Arrhenius model

For the calculation of the test duration for the "High-temperature durability testing" service life test, the percentage temperature load spectrum as per the use profile in the Performance Specification (see also table D.1)

Table D.1 – Temperature load spectrum

Temperature in °C	Distribution in %
$T_{\text{field},1}$	p_1
$T_{\text{field},2}$	p_2
$T_{\text{field},3}$	p_3
...	...
$T_{\text{field},n}$	p_n

and the operating duration $t_{\text{operation}}$ of the vehicle in the field, must be used.

For each temperature from $T_{\text{field},1} \dots T_{\text{field},n}$, an acceleration factor $A_{T,1} \dots A_{T,n}$ must be calculated using formula (D.1):

$$A_{T,i} = e^{\left[-\left(\frac{E_A}{k} \right) \times \left(\frac{1}{T_{\text{test}} + 273.15} - \frac{1}{T_{\text{field},i} + 273.15} \right) \right]} \quad (\text{D.1})$$

Legend

$A_{T,i}$	Acceleration factor of the Arrhenius model
E_A	Activation energy $E_A = 0,45 \text{ eV}$
k	Boltzmann constant ($k = 8,617 \times 10^{-5} \text{ eV/K}$)
T_{test}	Test temperature in °C, usually T_{max}
$T_{\text{field},i}$	Field temperature in °C, based on the temperature load spectrum according to the use profile
-273,15 °C	Absolute zero of temperature

The total test duration for high-temperature durability testing is yielded from the acceleration factors as per formula (D.2):

$$t_{\text{test}} = t_{\text{operation}} \times \sum_i \frac{p_i}{A_{T,i}} \quad (\text{D.2})$$

Legend

t_{test}	Test duration (in hours) for the "High-temperature durability testing" service life test
$t_{\text{operation}}$	Operating duration (in hours) in the field
p_i	Percentage share in operating duration during which the component is operated at temperature $T_{\text{field},i}$ in the field.
$A_{T,i}$	Acceleration factor for temperature $T_{\text{field},i}$

D.3 Example of Arrhenius model:

For an electronic control unit with the temperature load spectrum indicated in table D.2

Table D.2 – Example temperature load spectrum

Temperature in °C	Distribution in %
-40	6
23	20
60	65
100	8
105	1

and an operating duration of 8 000 h, the test duration for the "High-temperature durability testing" service life test is calculated as follows:

The acceleration factors $A_{T,i}$ for all five temperatures (see table D.2) of the temperature load spectrum indicated above are calculated using formula (C.1) and $T_{\text{test}} = T_{\text{max}} = 105 \text{ °C}$:

$$A_{T,1} = 5\,369$$

$$A_{T,2} = 45,8$$

$$A_{T,3} = 6,46$$

$$A_{T,4} = 1,20$$

$$A_{T,5} = 1,00$$

The operating duration of the component is $t_{\text{operation}} = 8\,000 \text{ h}$.

The total test duration of the "High-temperature durability testing" service life test is yielded as per formula (D.3):

$$t_{\text{test}} = 8\,000 \text{ h} \times \left(\frac{0.06}{5\,369} + \frac{0.20}{45.8} + \frac{0.65}{6.46} + \frac{0.08}{1.20} + \frac{0.01}{1.00} \right) = 1\,452 \text{ h} \quad (\text{D.3})$$

D.4 Arrhenius model to be used for components with reduced performance at high temperatures

For the calculation of the test duration of the "High-temperature durability testing" service life test for components with reduced performance at high temperatures at or above $T_{op,max}$, the temperature load spectrum according to the use profile given in the Performance Specification is divided into the two temperature ranges $T \leq T_{op,max}$ and $T > T_{op,max}$:

Table D.3 – Temperature load spectrum for $T \leq T_{op,max}$ with test temperature $T_{op,max}$

Temperature in °C	Distribution in %
$T_{field,1}$	p_1
$T_{field,2}$	p_2
$T_{field,3}$	p_3
...	...
$T_{field,m} (\leq T_{op,max})^a)$	$p_m^a)$
a) $m < n$	

Table D.4 – Temperature load spectrum for $T_{op,max} < T \leq T_{max}$ with test temperature T_{max}

Temperature in °C	Distribution in %
$T_{field,m+1} (> T_{op,max})^a)$	$p_{m+1}^a)$
$T_{field,m+2}^a)$	$p_{m+2}^a)$
$T_{field,m+3}^a)$	$p_{m+3}^a)$
...	...
$T_{field,n}^a)$	$p_n^a)$
a) $m < n$	

An acceleration factor $A_{T,1} \dots A_{T,m} \dots A_{T,n}$ is calculated for each temperature $T_{field,1} \dots T_{field,m} \dots T_{field,n}$ using formula (C.1), where a test temperature of $T_{test} = T_{op,max}$ is assumed for temperature range $T \leq T_{op,max}$, and a test temperature of $T_{test} = T_{max}$ is assumed for the temperature range $T > T_{op,max}$.

The required test duration $t_{op,max}$ at test temperature $T_{op,max}$ is yielded as per formula (C.2), where $i = 1 \dots m$.

The required test duration t_{max} at test temperature T_{max} is yielded as per formula (C.2), where $i = m + 1 \dots n$.

The total test duration t_{total} is the sum of $t_{op,max}$ and t_{max} .

For testing that is close to real-life conditions, the test is carried out intermittently at test temperatures $T_{op,max}$ or T_{max} (see figure 44).

The interval duration, which is typically 48 h, is divided based on the ratio of partial test durations $t_{op,max}$ and t_{max} .

D.5 Example Arrhenius model to be used for components with reduced performance at high temperatures

The temperature load spectrum as per table D.5 and table D.6 applies to the electronic control unit. For an operating duration of 8 000 h, the test duration for the "High-temperature durability testing" service life test for components with reduced performance at or above $T_{op,max} = 90\text{ °C}$ is calculated as follows:

The percentage temperature distributions according to the use profile is divided into two ranges $T \leq T_{op,max}$ and $T > T_{op,max}$.

**Table D.5 – Example load spectrum for
 $T \leq 90\text{ °C}$**

Temperature in °C	Distribution in %
-40	6
23	20
60	65

**Table D.6 – Example load spectrum for
 $T > 90\text{ °C}$**

Temperature in °C	Distribution in %
100	8
105	1

Using formula (C.1) and $T_{test} = 90\text{ °C}$, the acceleration factors $A_{T,i}$ are calculated for all temperatures $T \leq 90\text{ °C}$ (see table D.5) of the first part of the temperature load spectrum:

$$A_{T,1} = 3\,035,79$$

$$A_{T,2} = 25,88$$

$$A_{T,3} = 3,65$$

This yields a test duration $t_{op,max}$ at a test temperature of $T_{op,max} = 90\text{ °C}$ as per formula (D.4):

$$t_{op,max}(T_{test} = 90\text{ °C}) = 8\,000\text{ h} \times \left(\frac{0.06}{3\,035.79} + \frac{0.20}{25.88} + \frac{0.65}{3.65} \right) = 1\,487\text{ h} \quad (\text{D.4})$$

Using formula (C.1) and $T_{test} = 105\text{ °C}$, the acceleration factors $A_{T,i}$ are calculated for all temperatures $T > 90\text{ °C}$ (see table D.6) of the second part of the temperature load spectrum:

$$A_{T,4} = 1,20$$

$$A_{T,5} = 1,00$$

This yields a test duration t_{max} at a test temperature of $T_{max} = 105\text{ °C}$ as per formula (D.5):

$$t_{max}(T_{test} = 105\text{ °C}) = 8\,000\text{ h} \times \left(\frac{0.08}{1.20} + \frac{0.01}{1.00} \right) = 612\text{ h} \quad (\text{D.5})$$

The total test duration for the "High-temperature durability testing" service life test is yielded as the sum of the two test durations as per formula (D.6):

$$t_{\text{tot}} = t_{\text{op,max}} + t_{\text{max}} = 1\,487\text{ h} + 612\text{ h} = 2\,099\text{ h} \quad (\text{D.6})$$

The test is carried out as per figure 44 intermittently at test temperatures $T_{\text{op,max}}$ or T_{max} with the interval times from formula (D.7) and formula (D.8):

$$t_1 = 48\text{ h} \times \frac{t_{\text{op,max}}}{t_{\text{tot}}} = 48\text{ h} \times \frac{1\,487}{2\,099} = 34\text{ h} \quad (\text{D.7})$$

$$t_2 = 48\text{ h} \times \frac{t_{\text{max}}}{t_{\text{tot}}} = 48\text{ h} \times \frac{612}{2\,099} = 14\text{ h} \quad (\text{D.8})$$

D.6 Arrhenius model to be used for components on coolant circuits

D.6.1 General

In the case of components that are connected to the cooling circuit, all relevant operating situations i (see section 4.10; i corresponds to the consecutive situation number) must be taken into account with the associated ambient temperature and coolant circuit temperature distributions. For the "High-temperature durability testing" service life test, the test durations and test temperatures for the ambient temperature and the coolant circuit temperature must be calculated as described below for each relevant operating situation i ; the total test duration is yielded from the sum of the test durations for each relevant operating situation i .

For each relevant operating situation i , the test duration for the ambient temperature and the coolant circuit temperature must first be calculated separately according to the Arrhenius model as per section D.2 or section D.4, in order to calculate the test duration for operating situation i . Because the resulting test durations $t_{\text{test,ambient}}$ and $t_{\text{test,CC}}$ generally differ but the component can only be tested for the respective operating situation i with a uniform test duration, the test duration must be aligned between the ambient temperature and the coolant circuit temperature.

The shorter of the two test durations $t_{\text{test,ambient}}$ and $t_{\text{test,CC}}$ must be adapted to the longer test duration as per the following iteration method by dividing the test into at least two partial tests and lowering the test temperatures in all but one partial test.

D.6.2 Case A: $t_{\text{test,ambient}} < t_{\text{test,CC}}$

D.6.2.1 Test duration

For $t_{\text{test,ambient}} < t_{\text{test,CC}}$, the test duration for operating situation i is $t_{\text{test,situation } i} = t_{\text{test,CC}}$.

D.6.2.2 Test temperature (coolant)

The test temperature must be selected according to the Arrhenius model as per section D.2 (usually $T_{\text{cool,max}}$).

D.6.2.3 Test temperatures (ambient temperature)

The test temperatures must be calculated iteratively using the following algorithm, on the basis of the temperature load spectrum for the coolant temperature of operating situation i being considered (see table D.7).

**Table D.7 – Temperature load spectrum
(ambient temperature)**

Temperature in °C	Distribution in %
$T_{\text{field},1}$	p_1
$T_{\text{field},2}$	p_2
$T_{\text{field},3}$	p_3
...	...
$T_{\text{field},n}$	p_n

1. Start of iteration (m = 0):

The first partial test must be carried out at test temperature $T_{\text{field},n}$ for the partial test duration from formula (D.9):

$$t_{\text{test}_T \text{field},n} = t_{\text{operation}} \times p_n \quad (\text{D.9})$$

(where $t_{\text{operation}}$ corresponds to the operating duration in the field of operating situation i being considered, in hours).

2. First iteration (m = 1):

A portion of the test duration for operating situation i $t_{\text{test}, \text{situation } i}$ is covered by the 1st partial test so that a remaining test duration yet to be covered by the additional partial tests is yielded (see formula (D.10)):

$$t_{\text{remaining},1} = t_{\text{test}, \text{situation } i} - t_{\text{test}_T \text{field},n} \quad (\text{D.10})$$

In addition, the portion p_n of the temperature distribution of the ambient temperature is covered by the first partial test. Therefore, this portion p_n must be set to $p_n = 0$ for the further calculation.

To specify the test temperature for the 2nd partial test (m = 1), the test temperature T_{adapted} must first be determined using the Arrhenius model as per section D.1 or section D.4 in such a way that a test duration with the magnitude of the remaining test duration $t_{\text{remaining},1}$ results for the distribution (adapted with $p_n = 0$) of the ambient temperature.

If the adapted test temperature T_{adapted} determined in this way is less than $T_{\text{field},n-1}$, then the 2nd partial test must be performed at the test temperature $T_{\text{field},n-1}$ for the test duration from formula (D.11)

$$t_{\text{test}_T \text{field},n-1} = t_{\text{operation}} \times p_{n-1} \quad (\text{D.11})$$

and at least one additional iteration step must be carried out. If, on the other hand, the adapted test temperature T_{adapted} determined in this way is greater than $T_{\text{field},n-1}$, then the 2nd partial test must be performed at the test temperature T_{adapted} for the test duration from formula (D.12)

$$t_{\text{test}_T \text{field},n-1} = t_{\text{remaining},1} \quad (\text{D.12})$$

and an additional iteration step does not have to be carried out (end of iteration).

3. Additional iterations (m = 2, 3, ...)

A part of the test duration for operating situation i $t_{\text{test}, \text{situation } i}$ is covered by the first m partial tests, so that a remaining test duration yet to be covered by the additional partial tests is yielded from formula (D.13):

$$t_{\text{remaining},m} = t_{\text{test}, \text{situation } i} - \sum_{k=0}^{m-1} t_{\text{test}_T \text{field},n-k} \quad (\text{D.13})$$

In addition, the portions p_{n-k} with $k = 0, 1, \dots, (m - 1)$ of the temperature distribution of the ambient temperature are covered by the first m partial tests. Therefore, these portions p_{n-k} must be set to $p_{n-k} = 0$ for the further calculation.

To specify the test temperature for the $(m+1)$ th partial test, the test temperature T_{adapted} must first be determined using the Arrhenius model as per section D.1 or section D.4 in such a way that a test duration with the magnitude of the remaining test duration $t_{\text{remaining},m}$ results for the distribution (adapted with $p_{n-k} = 0$) of the ambient temperature.

If the adapted test temperature T_{adapted} determined in this way is less than $T_{\text{field},n-m}$, then the $(m+1)$ th partial test must be performed at the test temperature $T_{\text{field},n-m}$ for the test duration from formula (D.14)

$$t_{\text{test}_T \text{field},n-m} = t_{\text{operation}} \times p_{n-m} \quad (\text{D.14})$$

and at least one additional iteration step must be carried out. If, on the other hand, the adapted test temperature T_{adapted} determined in this way is greater than $T_{\text{field},n-m}$, then the $(m+1)$ th partial test must be performed at the test temperature T_{adapted} for the test duration from formula (D.15)

$$t_{\text{test}_T \text{field},n-m} = t_{\text{remaining},m} \quad (\text{D.15})$$

and an additional iteration step does not have to be carried out (end of iteration).

D.6.3 Case B: $t_{\text{test},\text{ambient}} > t_{\text{test},\text{CC}}$

D.6.3.1 Test duration

For $t_{\text{test},\text{ambient}} > t_{\text{test},\text{CC}}$, the test duration for operating situation i is $t_{\text{test},\text{situation } i} = t_{\text{test},\text{ambient}}$.

D.6.3.2 Test temperature (ambient temperature)

The test temperature must be selected according to the Arrhenius model as per section D.1 or section D.4 (generally T_{max} or T_{max} and $T_{\text{op, max}}$).

D.6.3.3 Test temperatures for ambient temperature

The test temperatures must be calculated iteratively using the following algorithm, on the basis of the temperature load spectrum for the coolant temperature of operating situation i being considered (see table D.8).

Table D.8 – Temperature load spectrum for coolant temperature

Temperature in °C	Distribution in %
$T_{\text{field},1}$	p_1
$T_{\text{field},2}$	p_2
$T_{\text{field},3}$	p_3
...	...
$T_{\text{field},n}$	p_n

1. Start of iteration (m = 0):

The first partial test must be carried out at test temperature $T_{\text{field},n}$ for the partial test duration from formula (D.16):

$$t_{\text{test}_T \text{field},n} = t_{\text{operation}} \times p_n \quad (\text{D.16})$$

(where $t_{\text{operation}}$ corresponds to the operating duration in the field of operating situation i being considered, in hours).

2. First iteration (m = 1):

A portion of the test duration for operating situation i $t_{\text{test},\text{situation } i}$ is covered by the 1st partial test so that a remaining test duration yet to be covered by the additional partial tests is yielded (see formula (D.17)):

$$t_{\text{remaining},1} = t_{\text{test},\text{situation } i} - t_{\text{test}_T \text{field},n} \quad (\text{D.17})$$

In addition, the portion p_n of the temperature distribution of the coolant temperature is covered by the first partial test. Therefore, this portion p_n must be set to $p_n = 0$ for the further calculation.

To specify the test temperature for the 2nd partial test (m = 1), the test temperature T_{adapted} must first be determined using the Arrhenius model as per section D.1 in such a way that a test duration with the magnitude of the remaining test duration $t_{\text{remaining},1}$ results for the distribution (adapted with $p_n = 0$) of the coolant temperature.

If the adapted test temperature T_{adapted} determined in this way is less than $T_{\text{field},n-1}$, then the 2nd partial test must be performed at the test temperature $T_{\text{field},n-1}$ for the test duration from formula (D.18)

$$t_{\text{test}_T \text{field},n-1} = t_{\text{operation}} \times p_{n-1} \quad (\text{D.18})$$

and at least one additional iteration step must be carried out. If, on the other hand, the adapted test temperature T_{adapted} determined in this way is greater than $T_{\text{field},n-1}$, then the 2nd partial test must be performed at the test temperature T_{adapted} for the test duration from formula (D.19)

$$t_{\text{test}_T \text{field},n-1} = t_{\text{remaining},1} \quad (\text{D.19})$$

and an additional iteration step does not have to be carried out (end of iteration).

3. Additional iterations (m = 2, 3, ...)

A part of the test duration for operating situation i $t_{\text{test},\text{situation } i}$ is covered by the first m partial tests, so that a remaining test duration yet to be covered by the additional partial tests is yielded from formula (D.20):

$$t_{\text{remaining},m} = t_{\text{test},\text{situation } i} - \sum_{k=0}^{m-1} t_{\text{test}_T \text{field},n-k} \quad (\text{D.20})$$

In addition, the portions p_{n-k} with $k = 0, 1, \dots, (m - 1)$ of the temperature distribution of the ambient temperature are covered by the first m partial tests. Therefore, these portions p_{n-k} must be set to $p_{n-k} = 0$ for the further calculation.

To specify the test temperature for the $(m+1)$ th partial test, the test temperature T_{adapted} must first be determined using the Arrhenius model as per [section D.1](#) in such a way that a test duration with the magnitude of the remaining test duration $t_{\text{remaining},m}$ results for the distribution (adapted with $p_{n-k} = 0$) of the coolant temperature.

If the adapted test temperature T_{adapted} determined in this way is less than $T_{\text{field},n-m}$, then the $(m+1)$ th partial test must be performed at the test temperature $T_{\text{field},n-m}$ for the test duration from [formula \(D.21\)](#)

$$t_{\text{test}_T_{\text{field},n-m}} = t_{\text{operation}} \times p_{n-m} \quad (\text{D.21})$$

and at least one additional iteration step must be carried out. If, on the other hand, the adapted test temperature T_{adapted} determined in this way is greater than $T_{\text{field},n-m}$, then the $(m+1)$ th partial test must be performed at the test temperature T_{adapted} for the test duration from [formula \(D.22\)](#)

$$t_{\text{test}_T_{\text{field},n-m}} = t_{\text{remaining},m} \quad (\text{D.22})$$

and an additional iteration step does not have to be carried out (end of iteration).

D.7 Example Arrhenius model to be used for components on coolant circuits

D.7.1 Temperature load spectrum

For an ECU connected to the coolant circuit, with the temperature load spectrum specified in [table D.9](#) and [table D.10](#) for the ambient temperature and the coolant temperature:

Table D.9 – Example ambient temperature load spectrum

Temperature in °C	Distribution in %
-40	6
23	20
50	65
100	8
105	1

Table D.10 – Example coolant temperature load spectrum

Temperature in °C	Distribution in %
-40	6
23	20
50	65
75	8
80	1

and an operating duration of 8 000 h, the test duration for the "High-temperature durability testing" service life test is calculated as follows:

D.7.2 Test duration

Calculation of the test durations for ambient temperature and coolant temperature using the Arrhenius model:

$$t_{\text{test,ambient}} = 1\,143 \text{ h}$$

$$t_{\text{test,CC}} = 2\,009 \text{ h}$$

As $t_{\text{test,ambient}} < t_{\text{test,CC}}$, the calculation is carried out as per [section D.6.2](#). The test duration for the ambient temperature must be adapted to $t_{\text{test,situation i}} = t_{\text{test,CC}} = 2\,009 \text{ h}$.

D.7.3 Test temperature (coolant)

The test temperature for the coolant is $T_{\text{CC,max}} = T_{\text{field, 5}} = 80 \text{ °C}$ as per the temperature load spectrum.

D.7.4 Iterative calculations for test temperatures for ambient temperature tests

1. Start of iteration

The first partial test is carried out at $T_{\text{field},5} = 105^\circ\text{C}$. The test duration as per formula (D.23) is:

$$t_{\text{test}_T \text{field},5} = t_{\text{operation}} \times p_5 = 8\,000\text{ h} \times 1\% = 80\text{ h} \quad (\text{D.23})$$

2. First iteration

A part of the test duration for the operating situation $i_{\text{test},\text{situation } i}$ has already been covered by the first partial test. The remaining test duration must therefore be recalculated using formula (D.24):

$$t_{\text{remaining},1} = t_{\text{test},\text{situation } i} - t_{\text{test}_T \text{field},5} = 2\,009\text{ h} - 80\text{ h} = 1\,929\text{ h} \quad (\text{D.24})$$

Because the portion p_5 of the temperature distribution is covered by the first partial test, p_5 is set to $p_5 = 0$ in the temperature distribution for the further calculation using the Arrhenius model as per table D.11.

Table D.11 – Adapted ambient temperature load spectrum after the 1st partial test

Temperature in °C	Distribution in %
-40	6
23	20
50	65
100	8

The test temperature T_{adapted} must be calculated using the Arrhenius model as per section C.1 in such a way that a test duration with the magnitude of the remaining test duration $t_{\text{remaining},1} = 1\,929\text{ h}$ results, to then be able to determine the test temperature for the 2nd partial test. Taking into account the adapted temperature distribution of the ambient temperature, the required test duration of 1 929 h results at a temperature of $T_{\text{adapted}} = 89,5^\circ\text{C}$ (exact value: $89,46^\circ\text{C}$).

However, because $T_{\text{adapted}} < T_{\text{field},4}$ (that is, $89,5^\circ\text{C} < 100^\circ\text{C}$), the 2nd partial test must be carried out at the test temperature $T_{\text{field},4} = 100^\circ\text{C}$.

According to formula (D.25), the test duration for the 2nd partial test is

$$t_{\text{test}_T \text{field},4} = t_{\text{operation}} \times p_4 = 8\,000\text{ h} \times 8\% = 640\text{ h} \quad (\text{D.25})$$

3. Second iteration

An additional part of the test duration for operating situation i , $t_{\text{test},\text{situation } i}$, was covered by the 2nd partial test, so the remaining test duration results from formula (D.26):

$$t_{\text{remaining},2} = t_{\text{test},\text{situation } i} - (t_{\text{test}_T \text{field},5} + t_{\text{test}_T \text{field},4}) = 2\,009\text{ h} - (80\text{ h} + 640\text{ h}) = 1\,289\text{ h} \quad (\text{D.26})$$

The portions p_5 and p_4 of the temperature load spectrum for the ambient temperature were already covered by the first two partial tests. Therefore, the portions must be set to $p_4 = p_5 = 0$ as per table D.12 for the additional iteration.

Table D.12 – Adapted ambient temperature load spectrum after the 1st and 2nd partial tests

Temperature in °C	Distribution in %
-40	6
23	20
50	65

The test temperature T_{adapted} must be calculated using the Arrhenius model as per section D.1 in such a way that a test duration with the magnitude of the remaining test duration $t_{\text{remaining},2} = 1\,289\text{ h}$ results, to then be able to determine the test temperature for the 3rd partial test. Taking into account the adapted temperature distribution of the ambient temperature, the required test duration of 1 289 h is yielded for the temperature $T_{\text{adapted}} = 82\text{ °C}$ (exact value: 82,17 °C).

As $T_{\text{adapted}} > T_{\text{field},3}$ (i.e., $82\text{ °C} > 50\text{ °C}$), no further iteration is required. Therefore, the third and final partial test is carried out for the test duration at $T_{\text{adapted}} = 82\text{ °C}$ as per formula (D.27).

$$t_{\text{test}_T\text{field},3} = t_{\text{remaining},3} = 1\,289\text{ h} \quad (\text{D.27})$$

In total, testing must be carried out for 80 h at 105 °C ambient temperature, for 640 h at 100 °C ambient temperature, and for 1 289 h at 82 °C ambient temperature. In this example, the coolant temperature is constant at 80 °C during the entire test duration.

Appendix E (normative) Calculation models for the "Temperature cycle durability testing" service life test

E.1 Adaptation of the test temperatures to reduce the test cycles

To reduce the number of test cycles for components that are actively operated in several operating situations, the test temperature T_{\max} (or $T_{CC,\max}$) can be increased to test individual operating situations relevant to the component. For this purpose, the absolute maximum temperature T_{\max} (or $T_{CC,\max}$) can be applied as the maximum test temperature for the operating situations relevant to the component. The component must remain fully functional here. It must also be ensured that all parts, subcomponents and materials that are part of the component are not operated outside of their respective specification limits (temperature limits), taking into account the self-heating generated by the component depending on the required operating mode.

The test temperature can be adapted for individual or multiple operating situations that are relevant to the component. The required number of test cycles must be calculated as per appendix D in each case.

Details concerning an increase in the test temperature and the resulting numbers of test cycles must be agreed upon between the purchaser and the contractor, and documented.

E.2 Coffin-Manson model

The calculation of the test duration for the "Temperature cycle durability testing" service life test is based on the average temperature change of the component in the field ΔT_{field} (see table B.1) and the number of temperature cycles during the service life in the field $N_{\text{tempcyclesfield}}$.

Two temperature changes per day are used for the number of temperature cycles in the field. Therefore, the following is yielded from formula (E.1):

$$N_{\text{TempCyclesField}} = 2 \times 365 \times 15 \text{ (years)} = 10\,950 \text{ cycles} \quad (\text{E.1})$$

Depending on the average temperature change in the field, the acceleration factor of the Coffin-Manson model is calculated as per formula (E.2):

$$A_{\text{CM}} = \left(\frac{\Delta T_{\text{test}}}{\Delta T_{\text{field}}} \right)^c \quad (\text{E.2})$$

Legend

A_{CM}	Acceleration factor of the Coffin-Manson model
ΔT_{test}	Temperature difference during a test cycle ($\Delta T_{\text{test}} = T_{\text{max}} - T_{\text{min}}$)
ΔT_{field}	Average temperature difference of the ambient temperature of the component at its point of use during the service life in the field
c	Parameter of the Coffin-Manson model A fixed value of 2,5 is used for c in this standard.

The total number of test cycles is calculated using formula (E.3):

$$N_{\text{test}} = \frac{N_{\text{TempCyclesField}}}{A_{\text{CM}}} \quad (\text{E.3})$$

Legend

N_{test}	Required number of test cycles
$N_{\text{TempCyclesFie}}$	Number of temperature cycles during the service life in the field
A_{CM}	Acceleration factor of the Coffin-Manson model as per formula (E.2)

E.3 Example

The number of test cycles (N_{test}) is calculated as follows for an electronic control unit with $T_{\text{min}} = -40\text{ °C}$ and $T_{\text{max}} = 105\text{ °C}$, a service life of 15 years in the field, and an average temperature difference in the field of $\Delta T_{\text{field}} = 40\text{ °C}$:

1. The number of temperature cycles in the field as per formula (E.4):

$$N_{\text{TempCyclesField}} = 2 \times 365 \times 15 \text{ (years)} = 10\,950 \text{ cycles} \quad (\text{E.4})$$

2. Temperature difference during a test cycle as per formula (E.5):

$$\Delta T_{\text{test}} = 105\text{ °C} - (-40\text{ °C}) = 145\text{ °C} \quad (\text{E.5})$$

3. The acceleration factor of the Coffin-Manson model is calculated as $A_{\text{CM}} = 25,02$ using formula (E.2).
4. Number of test cycles as per formula (E.6):

$$N_{\text{test}} = \frac{10\,950 \text{ cycles}}{25,02} = 438 \text{ cycles} \quad (\text{E.6})$$

5. The hold time consists of the time it takes for the component to reach a constant temperature throughout, plus 15 min. Assuming that the component has reached a constant temperature throughout after 20 min, the hold time is therefore 35 min.
6. Duration for a cycle as per formula (E.7):

$$t_{\text{cycle}} = 2 \times \left(\frac{(T_{\text{max}} - T_{\text{min}})}{4 \frac{\text{K}}{\text{min}}} + t_{\text{hold time}} \right) \quad (\text{E.7})$$

7. Therefore, the duration for a cycle in the example is as per formula (E.8):

$$t_{\text{cycle}} = 2 \times \left(\frac{(105\text{ °C} - (-40\text{ °C}))}{4 \frac{\text{K}}{\text{min}}} + 35 \text{ min} \right) = 142,5 \text{ min} \quad (\text{E.8})$$

8. For 438 cycles, the total test duration is therefore 1 040 h.

E.4 Coffin-Manson model to be used for components on coolant circuits

E.4.1 General

In the case of components that are connected to the coolant circuit, all relevant operating situations i (see section 4.10; i corresponds to the consecutive situation number) must be taken into account with their respective ambient and coolant circuit temperature rises. For the "Temperature cycle durability testing" service life test, the key temperatures and the number of test cycles must be calculated for each relevant operating situation i , as described below; the total number of test cycles is yielded from the sum of the partial numbers of test cycles for each relevant operating situation i .

For each relevant operating situation i , the numbers of test cycles for the ambient temperature and for the coolant circuit temperature must first be calculated separately according to the Coffin-Manson model as per section E.2, in order to calculate the number of test cycles for operating situation i . Because the resulting numbers of test cycles $N_{\text{test,ambient}}$ and $N_{\text{test,CC}}$ generally differ but the component can only be tested for the respective operating situation i with a uniform number of test cycles, the numbers of test cycles must be aligned between the ambient temperature and the coolant circuit temperature.

In doing so, the lower of the two numbers of test cycles $N_{\text{test,ambient}}$ and $N_{\text{test,CC}}$ must be adapted to the higher number of test cycles as per the following calculation, by splitting the test into three partial tests. One partial test is carried out with a full temperature rise between T_{min} and T_{max} ; the other two partial tests are carried out with a reduced temperature rise between T_{min} and T_{RT} , or between T_{RT} and T_{max} .

E.4.2 Test A: $N_{\text{test,ambient}} > N_{\text{test,CC}}$

E.4.2.1 Number of test cycles

For $N_{\text{test,ambient}} > N_{\text{test,CC}}$, the number of test cycles for operating situation i is $N_{\text{test,situation } i} = N_{\text{test,ambient}}$ cycles.

E.4.2.2 Number of test cycles for coolant temperature

The number of test cycles for the coolant $N_{\text{test,CC}}$ must be adapted to the greater number of test cycles for the ambient temperature $N_{\text{test,ambient}}$. The test cycles must be performed in the following three temperature ranges:

1. x_{CC} test cycles must be carried out between $T_{\text{CC,min}}$ and $T_{\text{CC,max}}$.
The acceleration factor $A_{\text{CM,CC,1}}$ is calculated as per the Coffin-Manson model with $\Delta T_{\text{test,1}} = T_{\text{CC,max}} - T_{\text{CC,min}}$.
2. $0,5 \times (N_{\text{test,situation } i} - x_{\text{CC}})$ test cycles must be carried out between $T_{\text{CC,min}}$ and T_{RT} .
The acceleration factor $A_{\text{CM,CC,2}}$ is calculated as per the Coffin-Manson model with $\Delta T_{\text{test,2}} = T_{\text{RT}} - T_{\text{CC,min}}$.
3. $0,5 \times (N_{\text{test,situation } i} - x_{\text{CC}})$ test cycles must be carried out between T_{RT} and $T_{\text{CC,max}}$.
The acceleration factor $A_{\text{CM,CCL,3}}$ is calculated as per the Coffin-Manson model with $\Delta T_{\text{test,3}} = T_{\text{CC,max}} - T_{\text{RT}}$.

In total, $N_{\text{test,situation } i}$ temperature cycles are yielded from 1. to 3.

Based on formula (E.3), this yields formula (E.9):

$$N_{TempCyclesField} = x_{CC} \times A_{CM,CC,1} + \frac{1}{2} \times (N_{test,situation\ i} - x_{CC}) \times A_{CM,CC,2} + \frac{1}{2} \times (N_{test,situation\ i} - x_{CC}) \times A_{CM,CC,3} \quad (E.9)$$

The number of test cycles x_{CC} is calculated from this as per formula (E.10):

$$x_{CC} = \frac{N_{TempCyclesField} - \frac{N_{test,situation\ i}}{2} \times (A_{CM,CC,2} + A_{CM,CC,3})}{A_{CM,CC,1} - \frac{1}{2} \times (A_{CM,CC,2} + A_{CM,CC,3})} \quad (E.10)$$

The numbers of test cycles for the three partial tests are obtained by inserting x_{CC} into points 1. to 3. listed above.

If $T_{CC,op,max} < T_{CC,max}$ or $T_{CC,op,min} > T_{CC,min}$ or $T_{ambient,op,max} < T_{ambient,max}$ or $T_{ambient,op,min} > T_{ambient,min}$, additional hold times must be taken into account for the respective temperatures as per figure 46.

The temperature cycles for the ambient temperature and for the coolant circuit temperature proceed synchronously during a test.

E.4.3 Case B: $N_{test,ambient} < N_{test,CC}$

Number of test cycles

For $N_{test,ambient} < N_{test,CC}$, the number of test cycles for operating situation i is $N_{test,situation\ i} = N_{test,CC}$.

E.4.4 Number of test cycles for ambient temperature:

The number of test cycles for the ambient temperature $N_{test,ambient}$ must be adapted to the greater number of test cycles for the coolant $N_{test,CC}$. The test cycles must be performed in the following three temperature ranges:

1. $x_{ambient}$ test cycles must be carried out between $T_{ambient,min}$ and $T_{ambient,max}$. The acceleration factor $A_{CM,ambient,1}$ is calculated as per the Coffin-Manson model with $\Delta T_{test,1} = T_{ambient,max} - T_{ambient,min}$.
2. $0,5 \times (N_{test,situation\ i} - x_{ambient})$ test cycles must be carried out between $T_{ambient,min}$ and T_{RT} . The acceleration factor $A_{CM,ambient,2}$ is calculated as per the Coffin-Manson model with $\Delta T_{test,2} = T_{RT} - T_{ambient,min}$.
3. $0,5 \times (N_{test,situation\ i} - x_{ambient})$ test cycles must be carried out between T_{RT} and $T_{ambient,max}$. The acceleration factor $A_{CM,ambient,3}$ is calculated as per the Coffin-Manson model with $\Delta T_{test,3} = T_{ambient,max} - T_{RT}$.

In total, $N_{test,situation\ i}$ temperature cycles are yielded from 1. to 3.

Based on formula (E.3), this yields formula (E.11):

$$N_{TempCyclesField} = x_{ambient} \times A_{CM,ambient,1} + \frac{1}{2} \times (N_{test,situation\ i} - x_{ambient}) \times A_{CM,ambient,2} + \frac{1}{2} \times (N_{test,situation\ i} - x_{ambient}) \times A_{CM,ambient,3} \quad (E.11)$$

The number of test cycles $x_{ambient}$ is calculated from this as per formula (E.12):

$$x_{\text{ambient}} = \frac{N_{\text{TempCyclesField}} - \frac{N_{\text{test,situation i}}}{2} \times (A_{\text{CM,ambient,2}} + A_{\text{CM,ambient,3}})}{A_{\text{CM,ambient,1}} - \frac{1}{2} \times (A_{\text{CM,ambient,2}} + A_{\text{CM,ambient,3}})} \quad (\text{E.12})$$

The numbers of test cycles for the three partial tests are obtained by inserting x_{ambient} into points 1. to 3. listed above.

If $T_{\text{ambient,op,max}} < T_{\text{ambient,max}}$ or $T_{\text{ambient,op,min}} > T_{\text{ambient,min}}$ or $T_{\text{CC,op,max}} < T_{\text{CC,max}}$ or $T_{\text{CC,op,min}} > T_{\text{CC,min}}$, additional hold times must be taken into account for the relevant temperatures as per figure 44.

The temperature cycles for the ambient temperature and for the coolant circuit temperature proceed synchronously during a test.

E.5 Example Coffin-Manson model to be used for components on coolant circuits

E.5.1 General

For an electronic control unit connected to the coolant circuit, with the ambient temperature range $T_{\text{ambient,min}} = -40\text{ °C}$ to $T_{\text{ambient,max}} = 120\text{ °C}$ and the coolant temperature range $T_{\text{CC,min}} = -40\text{ °C}$ to $T_{\text{CC,max}} = 80\text{ °C}$, a service life in the field of 15 years, an average temperature difference of the ambient in the field of $\Delta T_{\text{field,ambient}} = 60\text{ K}$, and an average temperature difference of the coolant in the field of $\Delta T_{\text{field,CC}} = 36\text{ K}$, the number of test cycles for an operating situation i is calculated as follows:

E.5.2 Number of test cycles for ambient temperature and coolant temperature

The calculation of the numbers of test cycles for the ambient temperature and for the coolant temperature according to the Coffin-Manson model as per section E.2 yields the following values:

$$N_{\text{test,ambient}} = 943 \text{ cycles}$$

$$N_{\text{test,CC}} = 540 \text{ cycles}$$

As $N_{\text{test,ambient}} > N_{\text{test,CC}}$, the number of test cycles for operating situation i is

$N_{\text{test,situation } i} = N_{\text{test,ambient}} = 943 \text{ cycles}$. The number of test cycles for the coolant temperature must be adapted.

E.5.3 Adapting the number of test cycles for the coolant temperature

The number of test cycles for the coolant temperature is adapted to $N_{\text{test,situation } i} = 943 \text{ cycles}$ in three parts:

1. x_{CC} test cycles must be carried out between $T_{\text{CC,min}} = -40\text{ °C}$ and $T_{\text{CC,max}} = 80\text{ °C}$. Acceleration factor $A_{\text{CM,CC,1}}$ is yielded from formula (E.13) as per the Coffin-Manson model:

$$A_{\text{CM,CC,1}} = \left(\frac{80\text{ °C} - (-40\text{ °C})}{36\text{ K}} \right)^{2.5} = 20.29 \quad (\text{E.13})$$

2. $0,5 \times (943 - x_{\text{CC}})$ test cycles must be carried out between $T_{\text{CC,min}} = -40\text{ °C}$ and $T_{\text{RT}} = 23\text{ °C}$. Acceleration factor $A_{\text{CM,CC,2}}$ is yielded from formula (E.14) as per the Coffin-Manson model:

$$A_{\text{CM,CC,2}} = \left(\frac{23\text{ °C} - (-40\text{ °C})}{36\text{ K}} \right)^{2.5} = 4.05 \quad (\text{E.14})$$

3. $0,5 \times (943 - x_{\text{CC}})$ test cycles must be carried out between $T_{\text{RT}} = 23\text{ °C}$ and $T_{\text{KKL,max}} = 80\text{ °C}$. Acceleration factor $A_{\text{CM,CC,3}}$ is yielded from formula (E.15) as per the Coffin-Manson model:

$$A_{\text{CM,CC,3}} = \left(\frac{80\text{ °C} - (-23\text{ °C})}{36\text{ K}} \right)^{2.5} = 3.15 \quad (\text{E.15})$$

This yields the following for x_{CC} as per formula (E.16):

$$x_{CC} = \frac{N_{TempCyclesField} - \frac{N_{test,situation\ i}}{2} \times (A_{CM,CC,2} + A_{CM,CC,3})}{A_{CM,CC,1} - \frac{1}{2} \times (A_{CM,CC,2} + A_{CM,CC,3})} = \frac{10\,950 - \frac{943}{2} \times (4.05 + 3.15)}{20.29 - \frac{1}{2} \times (4.05 + 3.15)} = 453 \text{ cycles} \quad (E.16)$$

Therefore, the following numbers of test cycles calculated as per points 1. to 3. are yielded for the three temperature ranges:

1. 453 cycles must be carried out between $T_{CC,min} = -40\text{ °C}$ and $T_{CC,max} = 80\text{ °C}$.
2. 245 cycles must be carried out between $T_{CC,min} = -40\text{ °C}$ and $T_{RT} = 23\text{ °C}$.
3. 245 cycles must be carried out between $T_{RT} = 23\text{ °C}$ and $T_{CC,max} = 80\text{ °C}$.

Adding the partial test cycles again yields the total number of test cycles for operating situation i
 $N_{test,situation\ i} = 943$ cycles.

The temperature cycles for the ambient temperature and for the coolant circuit temperature proceed synchronously during a test.

Appendix F (normative) Calculation models for the test Damp heat, constant - severity 2

F.1 Lawson model

The calculation of the test duration for the "Damp heat, constant - severity 2" test is based on the average ambient humidity $RH_{FieldParking}$ and the average ambient temperature $T_{FieldParking}$ of the component in the parked vehicle.

Unless otherwise defined in the Performance Specification, the following values must be used for the calculation:

Table F.1 – Average ambient humidity and ambient temperature in the parked vehicle

Point of use	Average ambient humidity $RH_{FieldParking}$	Average ambient temperature $T_{FieldParking}$
In the passenger compartment/luggage compartment	60% relative humidity	23 °C
Outside the passenger compartment/luggage compartment	65% relative humidity	23 °C

The acceleration factor of the Lawson model is calculated as per formula (F.1), as a function of the average ambient humidity and ambient temperature in the field:

$$A_{T/RH} = e^{\left[-\left(\frac{E_A}{k}\right) \times \left(\frac{1}{T_{test} + 273.15} - \frac{1}{T_{FieldParking} + 273.15}\right)\right]} + b \times [(RH_{test})^2 - (RH_{FieldParking})^2] \quad (F.1)$$

Legend

$A_{T/RH}$	Acceleration factor of the Lawson model
b	Constant ($b = 5,57 \times 10^{-4}$)
E_A	Activation energy ($E_A = 0,4$ eV)
k	Boltzmann constant ($k = 8,617 \times 10^{-5}$ eV/K)
T_{test}	Test temperature in °C
$T_{FieldParking}$	Average ambient temperature in °C
RH_{test}	Relative humidity in % during the test
$RH_{FieldParking}$	Average relative humidity in %
-273,15 °C	Absolute zero of temperature

The test duration for the "Damp heat, constant - severity 2" test is calculated using the following equation formula (F.2):

$$t_{test} = \frac{t_{FieldParking}}{A_{T/RH}} \quad (F.2)$$

Legend

t_{test}	Test duration in h
$t_{\text{FieldParking}}$	Non-operating duration (parking duration) in h during service life in the field (131 400 h in the worst-case scenario if the vehicle is not used)
$A_{T/RH}$	Acceleration factor of the Lawson model as per formula (F.1)

F.2 Example

For an electronic control unit installed in the engine compartment, the test duration is calculated as follows:

1. An average temperature of $T_{\text{FieldParking}} = 23\text{ °C}$ and a relative humidity of $RH_{\text{FieldParking}} = 65\%$ are assumed for the component in the parked vehicle.

The test conditions are $T_{\text{test}} = 65\text{ °C}$ and $RH_{\text{test}} = 93\%$.

Using formula (F.1), these values yield a combined acceleration factor of the Lawson model of $A_{T/RH} = 82,5$.

2. The parking duration in the field is $t_{\text{FieldParking}} = 131\,400\text{ h}$.

This yields the total test duration from formula (F.2) as formula (F.3):

$$t_{\text{test}} = \frac{131\,400\text{ h}}{82,5} = 1\,593\text{ h} \quad (\text{F.3})$$