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

Part 6:
Traction battery packs and systems

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

Partie 6: Packs et systèmes de batterie de traction

Reference number
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Foreword

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

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

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

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

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

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

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

Introduction

For over fifty years, traction batteries for electric vehicles have been developed to achieve high energy density and high power output. Specifically, lead-acid battery, Ni-Cd battery and Ni-MH battery with aqueous electrolyte were most applied to electric vehicles in the early days. Thermal activated batteries, such as molten salt batteries like sodium sulphur battery and Zebra battery were also examined. Lithium ion battery penetrated the consumer market in portable battery application from 1991. Currently, it is the most promising candidate of traction battery for electric vehicles. ISO 6469-1 specifies safety requirement of RESS (Rechargeable Energy Storage System) and the ISO 12405 series has been published to specify performance and reliability tests. This document focuses on environmental and endurance tests of lithium ion battery systems.

The ISO 19453 series specifies the test conditions on environment and reliability for electrical and electric equipment for the drive system of electric propulsion vehicles. The battery pack or system is the electric system which charges and discharges electricity through the converter. The test condition for mechanical load in ISO 19453-3 is too severe to apply to the battery pack or system from the standpoint of frequency range and amplitude of vibration in the test input spectrum. The test conditions for climatic load in ISO 19453-4 is also excessive to apply to the battery pack or system, because lithium ion battery pack is designed to control temperature within adequate operational range. That is the reason why appropriate conditions for the lithium ion battery are specified in this document.

The purpose of this document is to assist its user in systematically defining and/or applying a set of internationally accepted environmental conditions, tests and operating requirements, which are based on the anticipated actual environment in which the equipment will be operated and exposed to during its life cycle. This document has been developed based on fundamental investigations and vehicle measurements on voltage class A and B battery pack/system. The following environmental factors have been considered in the development of the ISO 19453 series.

— World geography and climate

Electric propulsion vehicles are operated in nearly all terrestrial regions of the earth. Significant variation in environmental conditions due to climatic environment, including diurnal and seasonal cycles, can therefore be expected. Consideration has been given to worldwide ranges in the temperature, humidity, precipitation and atmospheric conditions including dust, pollution and altitude.

— Type of electric propulsion vehicle

Operating environment in an electric propulsion vehicle can depend on its electric powertrain architecture as well as its mass, size, supply voltage and so on. Consideration has been given to typical types of series production electric propulsion vehicle architectures such as hybrid electric vehicles, battery electric vehicles, range extender hybrid electric vehicles and fuel cell vehicles, but not including equipment specific for fuel cell system.

— Vehicle use conditions and operating modes

Environmental conditions in and on the vehicle vary significantly with vehicle use (e.g. driving, charging during parking, etc.). Operating modes, such as starting, driving, braking, stopping and so on, have been considered, in particular, for traction battery system.

— Battery durability

For battery system, it is necessary to be resistant to environmental conditions experienced during manufacture, shipping, handling, storage, vehicle assembly, vehicle usage and vehicle maintenance and repair.

— Component mass and volume

The mass of battery pack is generally in the range of around 20 kg up to 60 kg for HEV, 80 kg to 150 kg for PHEV, more than 200 kg for BEV (weight assumptions from year 2020). The battery pack has generally a large volume and thermal capacity. It is necessary not only to prepare a large chamber but it will also take a long time to keep the thermal equivalent when performing a thermal shock test.

— Mounting location in the vehicle

HEV battery packs are generally installed inside the vehicle, PHEV battery packs are installed both outside and inside, and BEV battery packs are generally installed outside. The environmental condition such as water splashing, dust, salt spray, humidity or corrosion for battery packs installed outside vehicle interior is more severe than for battery packs installed inside. In this document, test conditions are specified according to mounting location.

a) Applicability to manufacturers' responsibility

Due to technology limitations or variations in vehicle design, the vehicle manufacturer may be required to place a component in a location where it cannot withstand the environmental conditions described in the ISO 19453 series. Under these circumstances, it is the responsibility of the vehicle manufacturer to provide the necessary environmental protection.

b) Applicability to wiring harnesses, cables and electrical connectors

Although some environmental conditions and tests in the ISO 19453 series may be relevant to vehicle wiring harnesses, cables and connectors, its scope is not sufficient to be used as a complete standard. It is therefore not recommended that the ISO 19453 series is directly applied to such devices and equipment.

c) Applicability to parts or assemblies inside equipment

The ISO 19453 series describes environmental conditions and tests to be applied to electrical and electronic equipment directly mounted in or on the vehicle. It is not intended for direct application to parts or assemblies that are part of the equipment. For example, the ISO 19453 series should not be directly applied to integrated circuits (ICs) and discrete components, electrical connectors, printed circuit boards (PCBs), gauges, etc. that are attached in or on the equipment. Electrical, mechanical, climatic and chemical loads for such parts and assemblies can be quite different from those described in the ISO 19453 series. Therefore, for those sub-components applying test conditions of the ISO 16750 series can be considered as a reference.

On the other hand, it is desirable to use the ISO 19453 series to help derive environmental conditions and test requirements for parts and assemblies that are intended for use in road vehicle equipment.

d) Applicability relative to system integration and validation

The user of the ISO 19453 series is cautioned to understand that its scope is limited to conditions and testing at the equipment level and therefore does not represent all conditions and testing necessary for complete verification and validation of the vehicle system, for example cold water shock tests were omitted from this document. Environmental and reliability testing of equipment parts and vehicle systems may be required. For example, the ISO 19453 series does not necessarily ensure that environmental and reliability requirements for solder joints, solderless connections, integrated circuits and so on are met. Such items are assured at the part, material or assembly level. Additionally, vehicle and system level testing might be required to validate the equipment in the vehicle application.

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

Part 6:
Traction battery packs and systems

1 Scope

This document specifies requirements for lithium-ion traction battery packs or systems used in battery electric, hybrid electric and fuel cell electric road vehicles. This document describes the most relevant environmental stresses and specifies tests and test boundary conditions. This document establishes a classification of battery packs or systems and defines different stress levels for testing when a classification is applicable and required. The objective of this document is to specify standard test procedures and conditions to enable the observation of the reliability of the lithium-ion traction battery in the vehicle.

This document specifies tests for a battery pack or system of voltage class A and B.

This document provides the necessary information to set up a dedicated test plan for a battery pack or system subject to agreement between the customer and supplier. If required, the relevant test procedures and/or test conditions can also be selected from this document.

NOTE This document only covers requirements and test conditions for a traction battery pack or system used in passenger cars.

2 Normative references

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

ISO 6469-3, *Electrically propelled road vehicles — Safety specifications — Part 3: Electrical safety*

ISO 6469-3:2018/Amd 1, *Electrically propelled road vehicles — Safety specifications — Part 3: Electrical safety — Amendment 1: Withstand voltage test for electric power sources*

ISO 9227, *Corrosion tests in artificial atmospheres — Salt spray tests*

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

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

ISO 19453-5, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles — Part 5: Chemical loads*

ISO 20653, *Road vehicles — Degrees of protection (IP code) — Protection of electrical equipment against foreign objects, water and access*

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

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

IEC 60068-2-38, *Environmental testing — Part 2-38: Tests — Test Z/AD: Composite temperature/humidity cyclic test*

IEC 60068-2-60, *Environmental testing — Part 2-60: Tests — Test Ke: Flowing mixed gas corrosion test*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19453-1, ISO 20653 and the following apply.

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

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

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

3.1
BMS
battery management system
electronic system that controls, manages, detects or calculates electric and thermal functions of the battery pack or system and that provides communication between the battery pack or system and other vehicle controllers

3.2
electric chassis
conductive parts of a vehicle that are electrically connected and whose potential is taken as reference

3.3
ITCS
internal temperature control system
internal thermal management system of a battery pack or system that can heat or cool the battery pack or system to a target temperature determined by the *BMS* (3.1)

EXAMPLE Liquid based heating/cooling system.

3.4
main contactor
electronic or mechanic switching/disconnect device for the battery pack or system *main power supply live part* (3.5)

3.5
main power supply live part
conductor or conductive part intended to be energized in normal use, but by convention not *the electric chassis* (3.2) or the class A auxiliary voltage supply

3.6
MAST
multiaxial simulation table
multiaxial system to induce vibrations or shocks in all three axial dimensions to the DUT

3.7
PSD
power spectral density
measure of signal's power content versus frequency

Note 1 to entry: A PSD is typically used to characterize broadband random signals. The amplitude of the PSD is normalized by the spectral resolution employed to digitize the signal.

3.8
rated capacity
total number of ampere-hours that can be withdrawn from a fully charged battery pack or system under test conditions defined by the battery pack or system manufacturer

3.9
technical tightness
inherent characteristic of a system that prevent fluids, gases or dusts from passing from the external to the internal environment or from the internal to the external environment, or both

4 Symbols and abbreviated terms

4.1 Symbols

1C	One-hour charge or discharge rate for the rated battery pack or system capacity.
C/3	Three-hour charge or discharge rate for the rated battery pack or system capacity.
RT	Room temperature value as defined in ISO 19453-1.
SOC_{max}	Maximum state of charge of a battery pack or system specified by the manufacturer.
SOC_{min}	Minimum state of charge of a battery pack or system specified by the manufacturer.
t_{ch}	Duration with an electrical current charging the battery pack or system.
t_{dch}	Duration with an electrical current discharging the battery pack or system.
T_{amb}	Ambient temperature of a climate/temperature chamber
T_{ITCS}	Temperature of the internal temperature control system, for example liquid coolant, of a battery pack or system.
T_{max}	Highest ambient temperature of a battery pack or system specified by the manufacturer (e.g. storage).
T^{*}_{max}	Maximum temperature by electric operation, can be lower than T_{max}
$T_{max, DUT}$	Highest operating temperature of a battery pack or system specified by the manufacturer.
$T_{max,ITCS}$	Highest temperature at which an internal temperature control system, for example liquid coolant, of a battery pack or system can be used. Specified by the manufacturer.
T_{min}	Lowest ambient temperature of a battery pack or system specified by the manufacturer (e.g. storage).
T^{*}_{min}	Low temperature, allows large currents, can be higher than T_{min}
$T_{min, DUT}$	Lowest operating temperature of a battery pack or system specified by the manufacturer.
$T_{min,ITCS}$	Lowest temperature at which an internal temperature control system, for example liquid coolant, of a battery pack or system can be used. Specified by the manufacturer.
X-axis	Vehicle driving direction.
Y-axis	Perpendicular to vehicle driving direction and vertical axis.
Z-axis	Vertical axis.

4.2 Abbreviated terms

CC/CV	Constant current /constant voltage
DOF	Degrees of freedom
DUT	Device under test. Referring to battery pack or system used for electrically propelled road vehicles
ITCS	Internal temperature control system
SOC	State of charge. Available capacity in a battery pack or system expressed as a percentage of rated capacity

5 Operating modes

5.1 General

An overview of the DUT operating modes according to this document is given in Table 1.

Operating modes defined in ISO 19453-1 cannot be applied because modes that are more specific are required for a battery pack or system.

Operation of the battery pack or system with autonomous functions, for example cell voltage balancing, in any of the operating modes shall be agreed between customer and supplier.

Table 1 — DUT operating modes

Operating mode	Class A auxiliary voltage	BMS	Main contactor	Electrical operation of main power supply live part	Internal temperature control system
5.1	Unsupplied	Non-operational	Open	No	Deactivated
5.2	Unsupplied	Non-operational	Open	No	Deactivated
6.1	Supplied	Non-operational	Open	No	Deactivated
6.2	Supplied	Operational	Open	No	Deactivated
6.3	Supplied	Operational	Closed	No	Deactivated
7.1	Supplied	Operational	Closed	Yes	Deactivated
7.2	Supplied	Operational	Closed	Yes	Activated

NOTE 1 Auxiliary voltage class A according to ISO 12405-4 refers to the voltage supply of the BMS with U_A or U_B as defined in ISO 19453-1.

NOTE 2 The difference between operating mode 5.1 and 5.2 is the presence of the wiring harness and the connection to all interfaces.

NOTE 3 The difference between operating mode 7.1 and 7.2 is that in operating mode 7.2 an ITCS is required due to self-heating effects caused by system activation.

NOTE 4 The conditions for an activated ITCS are set and controlled by the BMS regarding the thermal management strategy and the operational limits of the battery pack or system. If the ITCS is deactivated, it has no function. With deactivated ITCS, safety measures to limit the DUT temperature are still allowed at any time.

If the electronic control unit of a battery pack or system cannot provide the necessary BMS functionality, appropriate additional electric and/or electronic controllers to provide BMS functionality may be used in agreement between customer and supplier.

If the DUT has an internal temperature control system, the thermal management system and the corresponding conditioning loop at the test bench equipment shall be operational according to the given test specifications and controlled by the BMS. For the requested test procedure, the thermal management strategy and operational limits of the DUT shall be met.

Some test methods in this document require intended temperature settings for the ITCS beyond the thermal management strategy of the DUT controlled by the BMS. For these test procedures the thermal management system and conditioning loop at the test bench equipment is controlled externally by the test equipment according to the test specifications but within the battery system operational and safety limits.

If a liquid based internal temperature control system is used in the battery pack, the liquid circulating system shall be filled with the intended liquid (heat transfer medium) of the nominal volume and pressure. Up until operating mode 6.3 without use of the temperature control system, the openings can be sealed accordingly. If the fluid system is operated, the nominal flow rate as specified by the manufacturer should be used.

NOTE 1 For further information on the preparation of the DUT for testing, see ISO 12405-4:2018, 5.4.

NOTE 2 Pressure compensating devices can be needed for testing with liquid based internal temperature control systems.

5.2 Operating mode 5

No external voltages are applied to the DUT. The main contactor, if present, shall be opened.

- Operating mode 5.1
  - Not connected to wiring harness or any electrical interconnections or interfaces. Protective caps for the electrical interconnections and interfaces can be present.
- Operating mode 5.2
  - Connected to wiring harness including all electrical interconnections and interfaces simulating vehicle installation.

5.3 Operating mode 6

The DUT with all electrical connections made and connected to all interfaces is electrically operated with class A auxiliary supply voltage U_B as defined in ISO 19453-1, as in a vehicle with shut-off engine, but without operating load for the main power supply live part of the battery pack or system.

- Operating mode 6.1
  - BMS functions are not operational, no communication.
  - Battery pack or system shall be without electric operation (e.g. charging, discharging).
  - Main contactor, if present, shall be opened.
- Operating mode 6.2
  - BMS shall be fully operational according to the test specification.
  - Battery pack or system shall be without electric operation (e.g. charging, discharging).
  - Main contactor, if present, shall be opened.
- Operating mode 6.3
  - BMS shall be fully operational according to the test specification.
  - Battery pack or system shall be without electric operation (e.g. charging, discharging).
  - Main contactor, if present, shall be closed.

5.4 Operating mode 7

The DUT with all electrical connections made and connected to all interfaces is electrically operated with class A auxiliary voltage U_B as defined in ISO 19453-1 and with auxiliary machines, for example cooling system etc. The main contactor, if present, shall be closed.

— Operating mode 7.1

  — BMS shall be fully operational according to the test specification.

  — Battery pack or system with control in an electrical operating mode in which, if present, the ITCS is not operational.

— Operating mode 7.2

  — BMS shall be fully operational according to the test specification.

  — Battery pack or system shall be within control in a typical electrical operating mode, in which if needed, the ITCS is operational.

6 Functional status classification

Functional status classification is as defined in ISO 19453-1.

The verification of the required functional status takes place by means of continuous parameter monitoring or a parameter test.

Relevant control and test signals should be logged with sufficient resolution. Battery cycler and climate chamber data should be monitored

7 Functional status checks

7.1 Electrical requirements check

7.1.1 General

The tests described below are intended to ensure the insulation performance of the basic insulation measure of a voltage class B battery pack or system after completing environmental tests. The described tests shall be performed at the end of a sequence of environmental tests. If only a single environmental test is performed, they shall be performed afterwards.

NOTE 1 Performing the test sequence of an insulation resistance test followed by a withstand voltage test and finally a second insulation resistance test allows to determine whether the applied voltage level of the withstand voltage test had a permanent degrading effect on the insulation or not.

NOTE 2 Although not required for a voltage class A battery pack or system, the tests described in this section can technically also be applied to a voltage class A component, if applicable.

7.1.2 Equipotential bonding

This test ensures the required electrical resistances for equipotential bonding of conductively connected parts of the DUT. In particular as requirement for 7.1.3 and 7.1.4.

The equipotential bonding test shall be performed in accordance with ISO 6469-3.

The electrical resistance value shall meet the requirements of ISO 6469-3

7.1.3 Insulation resistance

This test measures the resistance value between main power supply live part and conductive parts of the DUT.

The insulation resistance test shall be performed in accordance with ISO 6469-3.

The insulation resistance value shall meet the requirements of ISO 6469-3.

7.1.4 Withstand voltage test

This test ensures the dielectric withstand voltage capability and detects pre-damaged parts of the insulation measure and weak points in the design, for example by conductive particles originating from production or rework, that could result in a failure of the insulation measure at later stages.

The withstand voltage test shall be performed in accordance with ISO 6469-3:2018/Amd 1.

The requirements of ISO 6469-3:2018/Amd 1 shall be met.

7.2 Mechanical requirements check

7.2.1 Technical tightness check of battery pack or system enclosure

The purpose of this test is to verify the technical tightness of the battery pack or system enclosure according to the desired degree of protection.

The method to check the technical tightness of the traction battery pack or system enclosure with specified degrees of protection in accordance with ISO 20653 via non-destructive tests and acceptance criteria shall be agreed between customer and supplier.

NOTE Non-destructive leak test techniques are listed in ISO 20653 or EN 1779. EN 13184, EN 13185 and EN 1593 support the implementation of techniques according to EN 1779.

The test method shall describe at least following items:

— technique used;

— pre-condition(s) (e.g. required room temperature, required acclimation time of the DUT at room temperature, condition of pressure compensation device);

— action(s);

— post condition(s);

— pass criteria;

— documentation content in test report;

— equipment.

7.2.2 Leak tightness check of internal temperature control system

The purpose of this test is to verify the leak tightness of the ITCS of the battery pack or system. The test shall only be performed if the DUT has a liquid medium for the ITCS, for example internal or external cooling-circuit.

The method for the leak test of the ITCS shall be agreed between customer and supplier.

The acceptance criteria shall be agreed between customer and supplier in order to satisfy the design requirement.

NOTE 1 This test can be performed with a pressure loss test, pressure difference, leakage volume or in accordance with EN 1779:1999, Annex A using a tracer gas in conjunction with a leak detector.

NOTE 2 An exemplary description a leak tightness check is given in Annex A.

8 Tests and requirements

8.1 Mechanical categories of battery packs or systems

Traction battery packs or systems for electric vehicles have a wide range of sizes and masses as well as a variety of mounting locations in the vehicle. Linked to these parameters is the strength of vehicle and DUT interaction, such as torsional forces. Taking all these factors into account, battery packs or systems shall be divided into three categories, as shown in Figure 1.

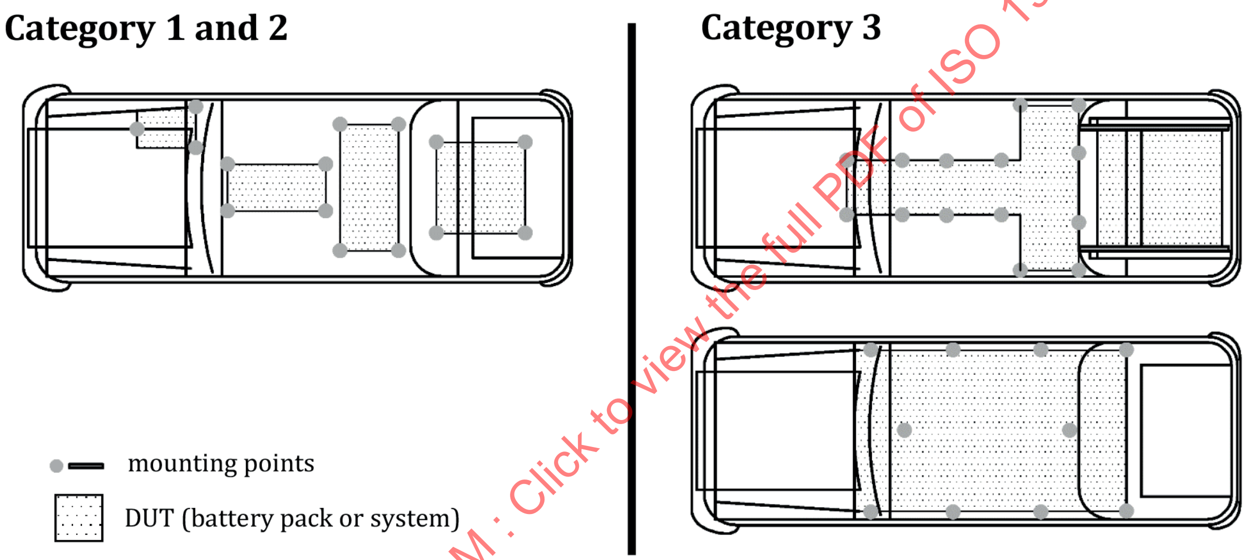


Figure 1 — Example of mechanical categorization and mounting locations

NOTE 1 The categorization according to mass is only meant as a rough guideline. An individual decision for a specific application which category is applicable can be made between customer and supplier, preferably based on vehicle measurements or simulations conducted by the customer.

NOTE 2 In case it is difficult to distinguish clearly between categories 2 and 3, a calculation of the vehicle body with and without the battery pack or system provides valuable information regarding resonance frequencies, stiffness, etc. If there is a significant difference in the calculation results with and without the battery pack or system, i.e. a strong interaction, the battery pack or system can be classified in category 3.

8.1.1 Category 1

This category is characterized by:

— local mounting in the vehicle (point-load);

— stiffness of vehicle body has no impact on DUT;

— no significant dynamic interaction of the DUT with the vehicle chassis;

— typical DUT mass ≤20 kg.

8.1.2 Category 2

This category is characterized by:

— local mounting in the vehicle (point-load);

— stiffness of vehicle body has secondary impact on DUT;

— low dynamic interaction of the DUT with the vehicle chassis;

— typical DUT mass >20 kg.

8.1.3 Category 3

This category is characterized by:

— large area mounting in the vehicle with different loads at different points of DUT;

— stiffness of vehicle body has primary impact on DUT;

— interaction with the vehicle chassis and dynamic stiffness;

— DUT can be part of the carrying vehicle structure (structurally integrated).

8.2 Pre-conditioning

8.2.1 General

The pre-conditioning is performed before a test to stabilize the DUT from mechanical strain and stress induced by the assembly process. If the same DUT is used in several tests, pre-conditioning is only performed once.

Whether pre-conditioning is necessary or not depends on the battery pack or system design and shall be agreed between customer and supplier (see Table 2).

Table 2 — Applicability of pre-conditioning

Test	Thermal pre-conditioning	Electrical pre-conditioning
8.3 Thermal cycling tests	N/A	N/A
8.4 Structural durability and strength tests	Mandatory	Mandatory
8.5 Water protection	Recommended	N/A
8.6 Dust protection	Recommended	N/A
8.7 Humid heat condensation test	Recommended	N/A
8.8 Damp heat, steady state test	Recommended	N/A
8.9.2 Mixed gas corrosion	Recommended	N/A
8.9.3 Salt-spray test for external mounting location	Recommended	N/A
8.9.4 Salt corrosion test for internal mounting location	Recommended	N/A
8.10 Chemical resistance	Recommended	N/A
N/A = not applicable.		

NOTE 1 Pre-conditioning is not intended to be a lifetime equivalent test.

NOTE 2 Pre-conditioning is used for ensuring the field status of the product at begin of service life.

8.2.2 Thermo-mechanical pre-conditioning

A thermo-mechanical pre-conditioning shall be performed by both thermal cycling and electrical operation, respectively.

NOTE The thermal and electrical pre-conditioning can be combined into a single test procedure.

8.2.2.1 Thermal pre-conditioning

Thermal pre-conditioning shall be performed as defined in 8.3.2 or 8.3.3 with at least four thermal cycles. The pre-conditioning clause depends on whether the battery pack or system has an internal temperature control system or not.

8.2.2.2 Electrical pre-conditioning

The electric load profile for the electrical pre-conditioning shall be determined by agreement between customer and supplier. An application specific load profile (drive cycle) or the electrical pre-conditioning in accordance with ISO 12405-4 should be used.

NOTE Electrical operation with an SOC change creates mechanical stress due to battery cell swelling or shrinking.

8.3 Thermal cycling tests

8.3.1 General

The purpose of these tests is to verify the reliability of the DUT with respect to changes in temperature. Out of the following tests, only the tests suitable for the DUT and its internal temperature control system (if present) shall be performed.

The DUT temperature shall be measured via the internal sensors and is determined by the BMS. The internal sensors shall measure the temperature at designated positions, for example on the cells or modules. Measurement points are not on the surface of battery pack outer casing. If no BMS is used for the determination of the DUT temperature, the DUT temperature shall be determined by the method agreed by customer and supplier.

Thermal cycles shall be performed in accordance with IEC 60068-2-14, Test Nb. The exposure time at the target temperature is the sum of the duration required for the thermal stabilization and a dwell time. Thermal stabilization of the DUT exposed to constant ambient temperature under operating conditions specified by tests can be terminated when the DUT temperature reaches the range of ±2 K to the target temperature value. An additional dwell time at the defined conditions shall be added to ensure thermal equilibrium throughout the DUT. Preliminary test shall be performed to determine the necessary dwell time, for example 60 min. If the time for thermal stabilization of the DUT is known, the thermal stabilization and dwell time, for example t_2 and t_4 in Table 3 and Table 4, can be agreed between customer and supplier as fix values. The temperature change rate shall be agreed between customer and supplier based on IEC 60068-2-14.

NOTE These tests are not intended to be lifetime equivalent tests. For product reliability according to the Coffin-Manson model either an application specific number of thermal cycles is required or critical design elements can be tested on module or sub-system level. An example is given in ISO 19453-1:2018, Annex B.

8.3.2 Thermal cycling for DUT without internal temperature control system

8.3.2.1 Purpose

This test checks the DUT for malfunctions and/or cracks and breakage caused by temperature gradients from ambient surroundings.

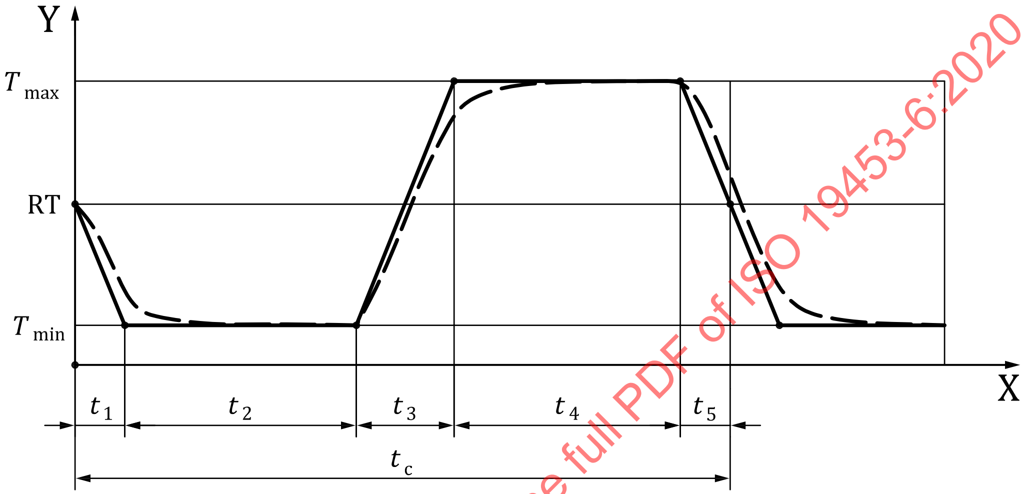
8.3.2.2 Test

Temperature cycling is performed according to 8.3.1.

Operating mode 6.2 shall be used.

The SOC of the battery pack or system shall be set to the value known to cause the highest level of stress in conjunction with a thermo-mechanical load, typically SOC_{max}.

Perform at least five temperature cycles of the temperature profile of Figure 2 between T_{min} and T_{max} in the ambient temperature. Temperature change of the DUT depends on the ambient environment.



Key

X time

Y temperature

T_{min} minimum ambient temperature

T_{max} maximum ambient temperature

RT room temperature

t_c one cycle

t_1, t_2, t_3, t_4, t_5 time parameter (in accordance with Table 3)

——— chamber temperature

— — — exemplary DUT temperature behaviour

Figure 2 — Temperature over time

Table 3 — Temperature over time

Parameter	Duration	Temperature
t_1	As agreed	From RT to T_{min}
t_2	Thermal stabilization and dwell time defined in 8.3.1	T_{min}
t_3	As agreed	From T_{min} to T_{max}
t_4	Thermal stabilization and dwell time defined in 8.3.1	T_{max}
t_5	As agreed	From T_{max} to RT
NOTE The time steps t_1 and t_5 can be considered a single time step that is equivalent to the time step t_3. The intention of the separation in t_1 and t_5 is to have the start and end of the temperature cycle at RT.		

8.3.2.3 Requirements

Malfunction and/or breakage shall not occur. Functional status shall be class A as defined in ISO 19453-1.

8.3.3 Thermal cycling for DUT with internal temperature control system

8.3.3.1 Purpose

This test checks the DUT for malfunctions and/or cracks and breakage caused by temperature gradients if an internal temperature control system is present. There are different technical realizations for ITCSs, for example liquid or airflow based. The applicability of this test shall be evaluated between customer and supplier.

8.3.3.2 Test

Temperature cycling is performed according to 8.3.1.

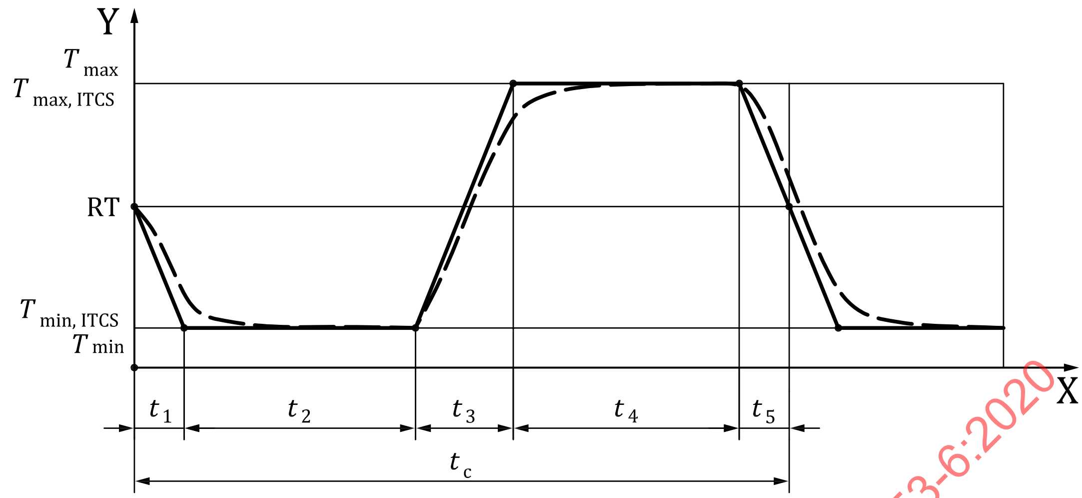
Operating mode 6.2 shall be used.

The SOC of the battery shall be set to the value known to cause the highest level of stress in conjunction with a thermo-mechanical load, typically SOC_{max}.

Perform at least five temperature cycles between T_{min}, $T_{min,ITCS}$ and T_{max}, $T_{max, ITSC}$ as illustrated in Figure 3 using both the ambient temperature and the internal temperature control system. Temperature control shall be conducted by combination via the ambient temperature control system of thermal test chamber and the internal temperature control system of the DUT.

For this test, the internal temperature control system shall be operational with the temperature set externally, not by the BMS.

In case $T_{max,ITCS}$ and $T_{min, ITCS}$ are different from T_{max} and T_{min}, the test condition shall be specified or determined between the customer and supplier.



Key

X	time
Y	temperature
T_{min}	minimum ambient temperature
$T_{min, ITCS}$	minimum temperature of the internal temperature control system
T_{max}	maximum ambient temperature
$T_{max, ITCS}$	maximum temperature of the internal temperature control system
RT	room temperature
t_c	one cycle
t_1, t_2, t_3, t_4, t_5	time parameter (in accordance with Table 4)
———	chamber temperature
— — —	exemplary DUT temperature behaviour

Figure 3 — Temperature over time

Table 4 — Temperature over time

Parameter	Duration	Temperature
t_1	As agreed	From RT to T_{min}
t_2	Thermal stabilization and dwell time defined in 8.3.1	T_{min}
t_3	As agreed	From T_{min} to T_{max}
t_4	Thermal stabilization and dwell time defined in 8.3.1	T_{max}
t_5	As agreed	From T_{max} to RT
NOTE The time steps t_1 and t_5 can be considered a single time step that is equivalent to the time step t_3. The intention of the separation in t_1 and t_5 is to have the start and end of the temperature cycle at RT.		

8.3.3.3 Requirements

Malfunction and/or breakage shall not occur. Functional status shall be class A as defined in ISO 19453-1.

8.3.4 Thermal cycling with electric operation

8.3.4.1 Purpose

This test checks the DUT for malfunctions and/or cracks and breakage caused by temperature gradients or temperature cycles of joint elements with a different coefficient of thermal expansion arising from electrical operation of the battery cells. A failure mechanism is, for example, thermo-mechanical stress due to Joule heating of resistive parts in the electrical current path, such as cell connectors, bus bars, etc.

For a battery pack or system where for a drive cycle an average low heat dissipation is expected, the applicability of the test shall be evaluated between customer and supplier.

8.3.4.2 Test

Temperature cycling is performed according to 8.3.1.

Operating mode 6.2 and 7.2 shall be used.

Perform at least five temperature cycles with electrical load within the main power supply live part with the DUT initially set to the target T^*_{min}, as illustrated in Figure 4.

— The DUT shall be cooled to the target temperature T^*_{min} in operating mode 6.2. The ambient temperature is kept at T^*_{min} for the complete test.

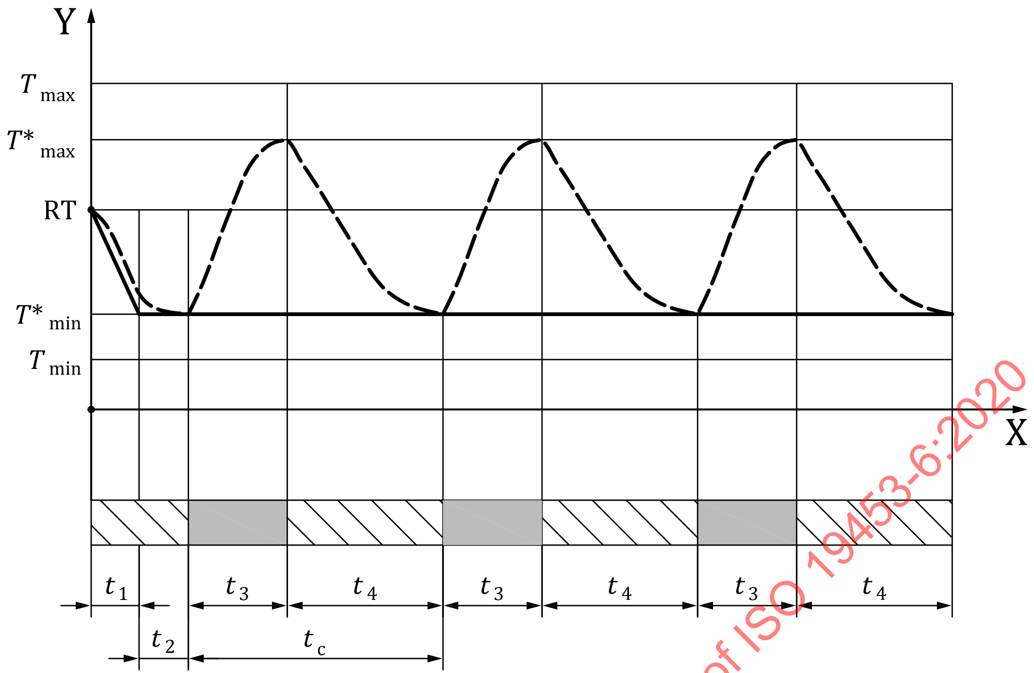
— After the DUT has reached the target temperature T^*_{min} the electrical dissipation in operating mode 7.2 shall be used to heat the DUT to a stable thermal state of T^*_{max}.

— After reaching thermal stable conditions operating mode 6.2 shall be used to re-cool the DUT to T^*_{min}.

The temperature T^*_{min} is determined with respect to the DUT specification to be able to operate the DUT with the highest available derated power output of the battery pack or system determined by the BMS.

The electric load profile for the main power supply live part in operating mode 7.2 shall be agreed between customer and supplier. The electric load profile should include charge and discharge current of the DUT. An example of a test scheme is given in Annex D.

The heat generated within the current path is correlated to both the absolute value of the electric current and the series resistances along the current path of the DUT. To maximize the thermal load, both the SOC and the temperature T^*_{min} of the DUT shall be chosen with respect to the system specifications to allow a maximum of electric current. Ideally, the maximum electric current value for both the charge and discharge direction is accessible simultaneously.



Key

X	time
Y	temperature
T_{min}	minimum ambient temperature
T_{max}	maximum ambient temperature
T^{*}_{min}	low temperature, allows large currents, can be higher than T_{min}
T^{*}_{max}	maximum temperature by electric operation, can be lower than T_{max}
t_c	one cycle
t_1, t_2, t_3, t_4	time parameter (in accordance with Table 5)
solid line	chamber temperature
dashed line	exemplary DUT temperature behaviour in phases with and without electrical operation
hatched box	Operating mode 6.2.
grey box	Operating mode 7.2.

Figure 4 — Temperature over time

Table 5 — Temperature over time

Parameter	Duration	Temperature	Electrical operation of main power supply live part
t_1	As agreed	From RT to T^{*}_{min}	No
t_2	Thermal stabilization and dwell time defined in 8.3.1	T^{*}_{min}	No
t_3	Thermal stabilization as agreed	T^{*}_{min} up to T^{*}_{max}	Yes
t_4	Thermal stabilization and dwell time defined in 8.3.1	From T^{*}_{max} to T^{*}_{min}	No
NOTE Time step t_1 ensures thermal equilibration of the DUT.			

NOTE 1 If the DUT is not equipped with an internal temperature control system and its mounting location is within the passenger or luggage compartment, RT can be used as T^{*}_{min} value.

NOTE 2 If the DUT is equipped with an internal active temperature control system, the operating temperature as specified by manufacturer can be used as T^*_{min}, as this typically guarantees optimal operating conditions for the battery cells.

8.3.4.3 Requirements

Malfunction and/or breakage shall not occur. Functional status shall be class A as defined in ISO 19453-1.

8.4 Structural durability and strength tests

8.4.1 General

The tests for the structural durability and strength consist of three parts and shall be performed with the same DUT in the following sequential order or as agreed between customer and supplier:

— pre-conditioning;

— durability test;

— mechanical shock.

Interlocking mechanical shock tests during the durability test schedule is permitted as follows. Durability test in X-axis followed by mechanical shocks in X-axis and similar sequence for Y- and Z-axis.

Performing half the required number of shocks before and remaining half after the durability tests is also permitted.

NOTE It can be valuable to measure the resonance frequency change by conducting a resonance sweep with sinusoidal excitation in accordance with IEC 60068-2-6 before and after each tested axis of the structural durability and strength test.

8.4.2 Fixture

The whole battery pack or system is mounted on a base plate according to the mounting location and orientation in the vehicle.

The type of fixture and mounting equipment of Table 6 shall be used, depending on the category of the battery pack or system according to 8.1.

Table 6 — Fixture type for structural durability and strength test depending on DUT category

Battery pack or system category	Fixture type
1	Rigid mounting on the base plate
2	As agreed between customer and supplier: rigid mounting on the base plate or vehicle mounting equipment, such as carrying frame or brackets, according to the given drawing instructions by the manufacturer
3	Vehicle mounting equipment, such as carrying frame or brackets, according to the given drawing instructions by the manufacturer

8.4.3 Pre-conditioning for mechanical tests

The thermo-mechanical pre-conditioning described in 8.2.2 shall be performed.

The pre-conditioning can be performed on a separate test equipment.

8.4.4 Durability test

8.4.4.1 Purpose

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

8.4.4.2 General

Subject the DUT during the durability test to a random vibrational load in combination with both thermal cycling according to 8.4.4.4 and electrical operation according to 8.4.4.5.

In the vehicle, vibration stress occurs in combination with different SOC states of the battery in addition to the combination of low or high temperatures. With different SOC values a change in volume of the battery cells can generally occur. The interaction between electro-mechanical and thermo-mechanical strain is included in the test. The main failure to be identified by this test is breakage due to fatigue, for example a battery cell or a part of a system/component which loosens or softens due to the high temperature and/or by electrical operation and cannot withstand the vibration load under this condition.

8.4.4.3 Mechanical load

The type of durability test and type of load signal in Table 7 depends on the category of the battery pack or system according to 8.1.

The durability test shall be performed in all three mutually perpendicular axes of the DUT in the sequential order X, Y and Z-axes or as agreed between customer and supplier, with the control parameters listed in Table 8.

Vehicle specific PSD profiles may be used for category 1 and 2 as alternative to the PSD profiles specified below. For category 3, vehicle specific profiles are required. In case of using vehicle specific profiles, test duration shall be determined in agreement between customer and supplier.

Durability tests with additional loads according to design, for example suspension forces, may be required if DUT is a part of the carrying structure of the vehicle. For testing of additional loads, see Annex B.

NOTE The test conditions of the PSD load spectrum and test duration can be adjusted according to the Basquin model. For an explanation, see ISO 19453-3:2018, A.6.

Table 7 — Mechanical load

	Category 1	Category 2	Category 3
Test method	Uniaxial shaker in X, Y, Z-direction	Uniaxial shaker in X, Y, Z-direction or MAST	Uniaxial shaker in X, Y, Z-direction or MAST Additional loads, including but not limited to torsion and bending, if necessary.
Test profile	PSD profiles for category 1 or vehicle specific profiles	PSD profiles for category 2 or vehicle specific profiles	Vehicle specific profiles and testing time or vehicle specific time signals

Table 8 — Control parameters for random vibration test

Statistical DOF	Minimum 120
Minimum frequency resolution	(1,25 ± 0,25) Hz
Sigma limiting	3 σ
Warning limits	±3 dB
Abort limits	±6 dB
NOTE Sigma limiting avoids out of band excitations, which can occur when using ‘harder’ sigma clipping. Sigma limiting is a ‘softer’ form of sigma clipping.	

8.4.4.3.1 Vibrational load profile for category 1

The test shall be performed in accordance with IEC 60068-2-64. Use a duration of 40 h for each axis of the DUT.

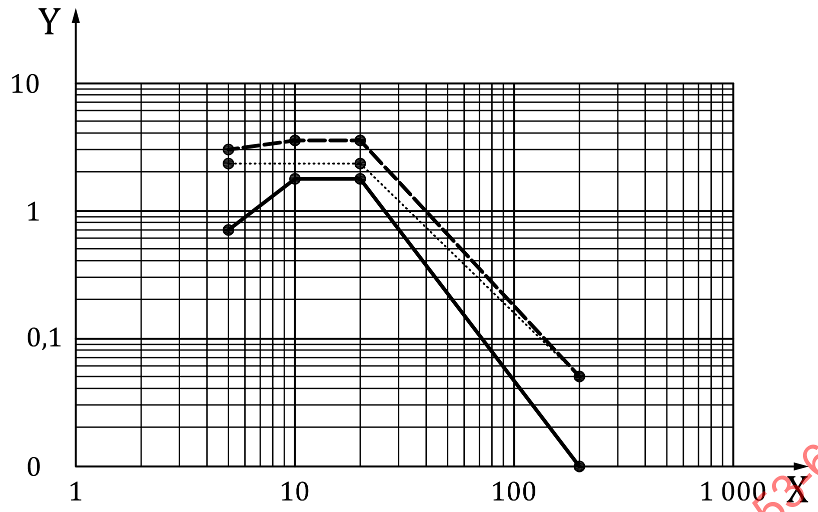
The rms acceleration values for the three primary axes are:

— X: 7,25 m/s^2;

— Y: 9,54 m/s^2;

— Z: 11,15 m/s^2.

The PSD versus frequency is illustrated in Figure 5 with values defined in Table 9 to Table 11.



Key

X frequency [Hz]

Y PSD [(m/s²)²/Hz]

curve for X-axis (in accordance with Table 9)

curve for Y-axis (in accordance with Table 10)

curve for Z-axis (in accordance with Table 11)

Figure 5 — PSD of acceleration versus frequency

Table 9 — Values of PSD and frequency for the X-axis

Frequency [Hz]	**PSD** [(m/s²)²/Hz]
5	0,741
10	1,790
20	1,790
200	0,012 0

Table 10 — Values of PSD and frequency for the Y-axis

Frequency [Hz]	**PSD** [(m/s²)²/Hz]
5	2,377
20	2,377
200	0,050 0

Table 11 — Values of PSD and frequency for the Z-axis

Frequency [Hz]	**PSD** [(m/s²)²/Hz]
5	2,983
10	3,580
20	3,580
200	0,050

8.4.4.3.2 Vibrational load profile for category 2

The test shall be performed in accordance with IEC 60068-2-64. Use a duration of 40 h for each axis of the DUT.

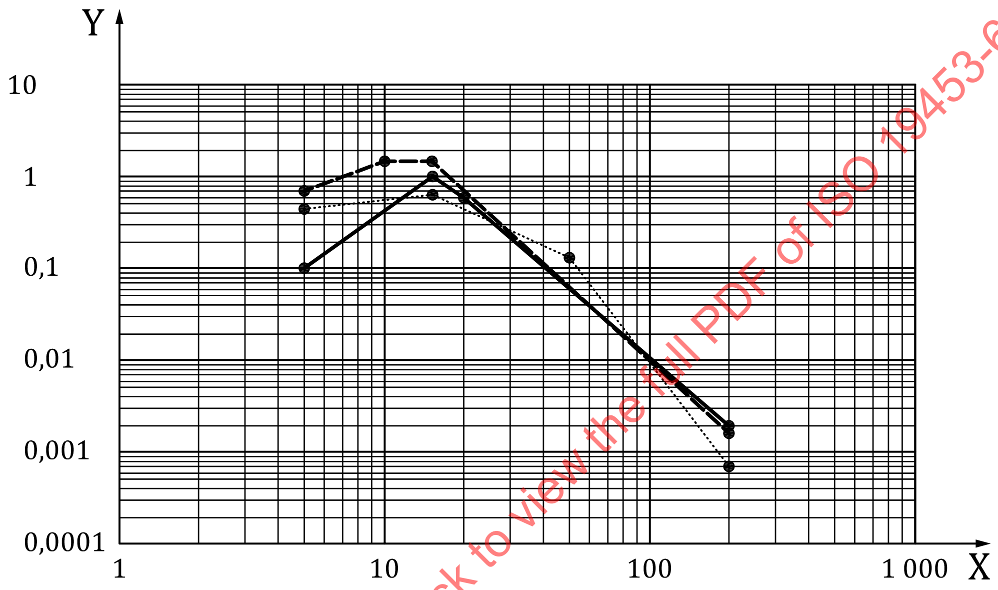
The rms acceleration values for the three primary axes are:

— X: 4,01 m/s^2;

— Y: 4,25 m/s^2;

— Z: 5,19 m/s^2.

The PSD versus frequency is illustrated in Figure 6 with values defined Tables 12 to 14.



Key

X frequency [Hz]

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

curve for X-axis (in accordance with Table 12)

curve for Y-axis (in accordance with Table 14)

curve for Z-axis (in accordance with Table 14)

Figure 6 — PSD of acceleration versus frequency

Table 12 — Values of PSD and frequency for the X-axis

Frequency [Hz]	PSD [(m/s^2)^2/Hz]
5	0,098
15	0,968
20	0,601
200	0,001 9

Table 13 — Values of PSD and frequency for the Y-axis

Frequency [Hz]	PSD [$(m/s^2)^2/Hz$]
5	0,469
15	0,663
50	0,135
200	0,000 7

Table 14 — Values of PSD and frequency for the Z-axis

Frequency [Hz]	PSD [$(m/s^2)^2/Hz$]
5	0,713
10	1,581
15	1,496
200	0,001 64

8.4.4.3.3 Vibrational load profile for category 3

The test may be performed as an operation load simulation test based on vehicle measurements. For the test, the overall mechanical load shall not be below the mechanical load measured in the real reference vehicle. The verification may be provided by calculation. For this calculation, the damage calculated from the mechanical load applied in the test shall be larger than the damage caused by the vibrational loads during vehicle measurements.

NOTE For further explanation for a damage calculation see ISO 19453-3:2018, Annex A.

8.4.4.4 Thermal cycling

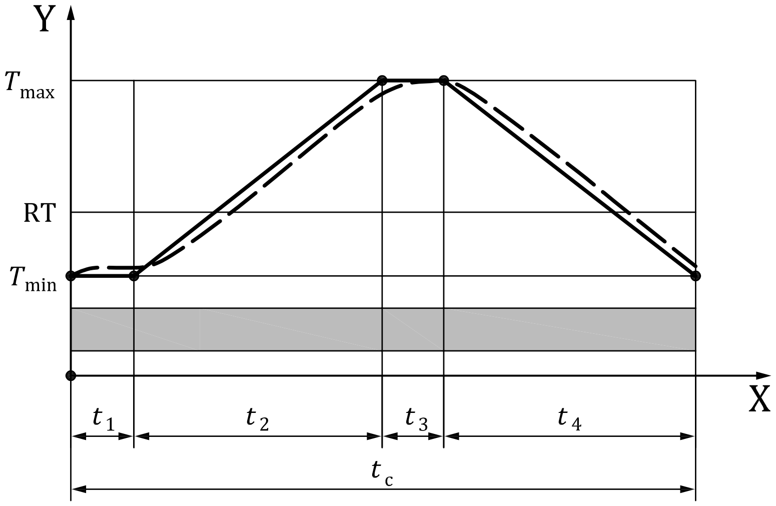
The temperature profile Figure 7 of and Table 15 shall be superimposed on the vibrational load cycle of 8.4.4.3.

For a battery pack or system with a typical operating temperature T_{typ} the temperature profile of Figure 8 and Table 16 can be used alternatively. The temperature T_{typ} is specified by the manufacturer.

Prior to test start, the DUT shall be cooled down to T_{min}. If the necessary cooling time is known, a fixed time can be used, for example 10 h.

At the target temperatures of the profiles, a full change in SOC by electrical operation from SOC_{min} to SOC_{max} or vice versa should be traversed. Due to derating, the electrical current might be reduced and hence a full charge or discharge may no longer be possible.

Measures to avoid overheating of the DUT during high-temperature operation with self-heating effects are allowed, for example by using an internal temperature control system.



Key

X time

Y temperature

T_{min} minimum ambient temperature

T_{max} maximum ambient temperature

RT room temperature

t_c one thermal cycle or complete duration of vibrational load excitation, for example 40 h for category 1 and category 2

t_1,t_2,t_3,t_4 time parameter (in accordance with Table 15)

——— chamber temperature

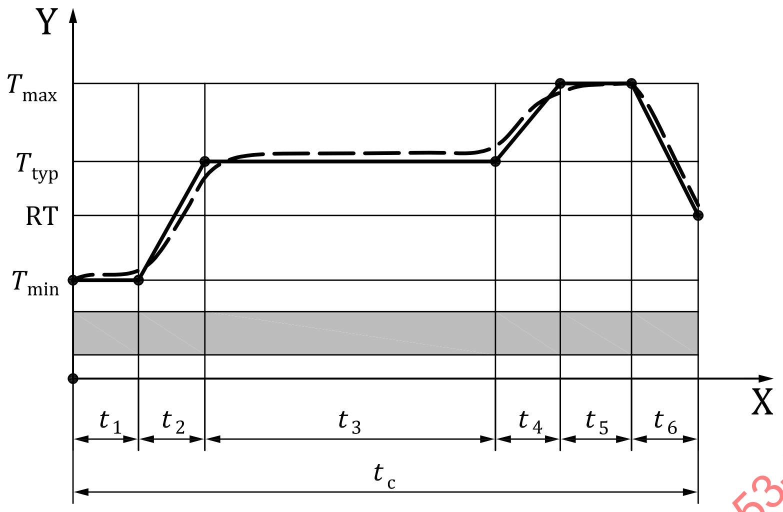
– — – exemplary DUT temperature behaviour

[grey box] active operation

Figure 7 — Temperature over time

Table 15 — Temperature versus time for the vibration test

Parameter	Duration [min]	Temperature	Electrical operation of main power supply live part
t_1	120	T_{min}	Yes
t_2	480	From T_{min} to T_{max}	Yes
t_3	120	T_{max}	Yes
t_4	480	T_{max} to T_{min}	Yes
The thermal cycle is either conducted twice or scaled to 40 h.			



Key

X time

Y temperature

T_{min} minimum ambient temperature

T_{max} maximum ambient temperature

RT room temperature

T_{typ} typical operating temperature specified by the battery pack or system manufacturer of actively cooled or heated systems

t_c complete duration of vibrational load excitation, for example 40 h for category 1 and category 2

t_1,t_2,t_3,t_4,t_5,t_6 time parameter (in accordance with Table 16)

(solid line) chamber temperature

(dashed line) exemplary DUT temperature behaviour

(grey box) active operation

Figure 8 — Temperature over time

Table 16 — Temperature versus time for the vibration test

Parameter	Duration [min]	Temperature	Electrical operation of main power supply live part
t_1	120	T_{min}	Yes
t_2	240	From T_{min} to T_{typ}	Yes
t_3	1 320	T_{typ}	Yes
t_4	240	From T_{typ} to T_{max}	Yes
t_5	240	T_{max}	Yes
t_6	240	From T_{max} to RT	Yes

8.4.4.4.1 Strategy for DUTs with internal temperature control systems

If the DUT is equipped with an internal temperature control system, that can be operated, the temperature shall be adjusted to follow the ambient temperature profile of Figure 7 or Figure 8.

8.4.4.5 Electrical operation

The electrical load profile superimposed on the vibrational load cycle of 8.4.4.3 and the thermal overlay of 8.4.4.4 shall be determined by agreement between customer and supplier.

Operating mode 7.1 or 7.2 shall be used.

An application specific load profile (drive cycle) should be used. Alternatively, a continuous cycling with standard charge and discharge cycles in accordance with ISO 12405-4 but without rest times may be used.

An example for combined thermal and electrical profile is given in Annex C.

Combined vibrational and thermal load shall be performed with electrical operation. Acquisition of sensor readings is allowed. The SOC cycling may be omitted from the combined test, if technical justification by pre-tests or simulations and technical assessment (e.g. design FMEA) prove that changes in SOC have no significant influence on the mechanical stress / strain level.

NOTE 1 A length of the wiring harness to the first fixation point on the test equipment, for example shaker base plate, representative of the vehicle mounting is used to avoid damage to the wiring harnesses and electrical connections.

NOTE 2 The specified electrical load profile can be adjusted by derating, for example at T_{min} or T_{max}.

8.4.4.6 Requirements

Breakage shall not occur. The functional status shall be class A as defined in ISO 19453-1.

8.4.5 Mechanical shock

8.4.5.1 Purpose

This test checks the DUT for malfunctions and breakage caused by mechanical shocks to the vehicle. Failure mode is mechanical damage. The load occurs, for example when driving over a kerbstone at high speed.

8.4.5.2 General

The mechanical shock test shall be performed at both SOC_{min} and SOC_{max} to cover the most severe considered condition for the DUT, for example SOC_{max} for obtaining a high tensile strain within the battery cell retainer or SOC_{min} leading to a minimum force between the battery cells and their encasing structure.

If there is technical justification, mechanical shock test at single SOC is permitted as agreed between customer and supplier. If only a single SOC is used, the most severe condition shall be used.

8.4.5.3 Test

The mechanical shock load profile of Table 17 depends on the category of the battery pack or system according to 8.1. The shock load cycles shall be performed according to IEC 60068-2-27.

Alternatively, for the shock duration and amplitude data from vehicle measurements may be used.

The shock acceleration shall be orientated in direction of the three mutually perpendicular axes of the DUT and shall be performed in the following sequential order of X-axis, Y-axis and Z-axis or as agreed between customer and supplier.

The total number of shocks is divided in equal quantity to shocks with the DUT discharged to SOC_{min} and charged to SOC_{max}. The charging or discharging procedure between the shocks at SOC_{min} and SOC_{max} shall be agreed between customer and supplier.

In between consecutive shock excitations a hold time shall be introduced suffice to completely attenuate the DUT oscillation at its natural frequency.

For obtaining the optimal set of machine control parameters, pre-shocks may be performed at reduced load amplitude, for example at −12 dB, −6 dB and −3 dB of the nominal mechanical shock profile.

Table 17 — Mechanical Shock load for DUTs of category 1 to 3

	Category 1	Category 2	Category 3
Shock wave form	Half-sinusoidal		
Shock duration	6 ms or OEM specific		
Number of shocks at SOC_{min}	3 per test direction ±X, ±Y, ±Z (total 18)		
Number of shocks at SOC_{max}	3 per test direction ±X, ±Y, ±Z (total 18)		
Acceleration	X: 196,2 m/s^2 or OEM specific Y: 127,53 m/s^2 or OEM specific Z: 294,3 m/s^2 or OEM specific	X: 176,58 m/s^2 or OEM specific Y: 98,1 m/s^2 or OEM specific Z: 245,25 m/s^2 or OEM specific	X: 147,15 m/s^2 or OEM specific Y: 78,48 m/s^2 or OEM specific Z: 196,2 m/s^2 or OEM specific
Operating mode	Operating mode 6.3		

8.4.5.4 Requirements

Breakage shall not occur. Functional status shall be class A as defined in ISO 19453-1.

8.4.6 Requirements

For the test sequence of mechanical shock and durability test with the same DUT, breakage shall not occur. Functional status shall be class A as defined in ISO 19453-1.

8.5 Water protection

8.5.1 Test

Perform the test in accordance with ISO 20653 regarding the degrees of protection (IP code) of the DUT enclosure.

The degrees of protection (IP code) of the DUT enclosure shall be determined under the agreement between customer and supplier.

Operating mode 6.2 shall be used, for example for read out of internal sensors. Alternatively, operating mode 5.2 can be used, if valid reasons are given, for example there is no BMS in the DUT.

The DUT shall be set to a suitable SOC under the agreement between customer and supplier, before the beginning of test in order to prevent a deep discharge of the DUT.

A non-conducting colorant may be used in order to colour the test medium and highlight water intrusion(s) in the enclosure due to this test. The colourant shall not impair the function of a pressure compensation device(s).

As test medium, tap water may be used.

8.5.2 Requirements

The functional status shall be class A as defined in ISO 19453-1. IP degree requirement shall meet at least ISO 20653.

8.6 Dust protection

8.6.1 Test

The test shall be performed as defined in ISO 19453-4 regarding the degrees of protection (IP code) of the DUT enclosure in accordance with ISO 20653, which is agreed between customer and supplier.

For a battery pack or system with IP class IP5KX the alternative test dust defined in ISO 19453-4 shall be used.

For a battery pack or system with IP class IP6KX the Arizona dust type shall be used.

Additional checks for the functional status should be performed after the test end, for example after 24 h.

NOTE A mechanical durability and strength test after the dust protection test with the same DUT addresses additional failure mechanisms due to possible ingress of conductive particles.

8.6.2 Requirements

The functional status shall be class A as defined in ISO 19453-1. IP degree requirement shall meet at least ISO 20653.

8.7 Humid heat condensation test

8.7.1 Purpose

This test simulates the thermal load (including frost) of the DUT by cyclic temperature changes with high humidity during vehicle operation. It is meant to verify the resistance of the DUT to damp heat and condensation.

NOTE This test is not intended to be a lifetime equivalent test.

8.7.2 Test

This test shall be performed according to IEC 60068-2-38 using the variant described below. For a battery pack or system the deviations and additional requirements to IEC 60068-2-38 are necessary because of its special behaviour as a power source.

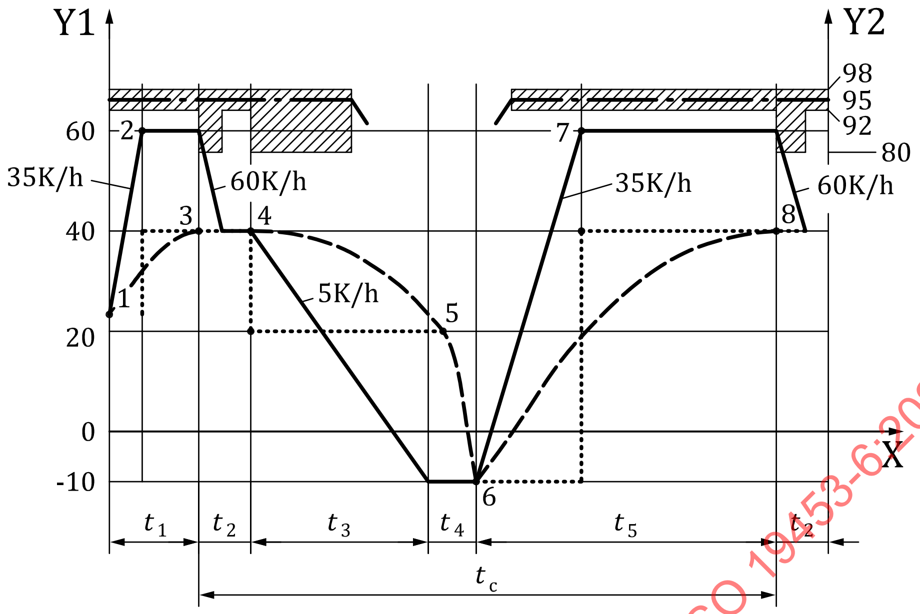
Perform at least five cycles of the temperature and humidity profile defined in Figure 9 and Table 18 using both the ambient temperature and the internal temperature control system, if present.

Operating mode 6.1 shall be used. For the functional check during the test, other operating modes can apply.

If the DUT is equipped with an internal temperature control system, for this test the internal temperature control system shall be operational with the temperature set externally, not by the BMS.

If the DUT is not equipped with an internal temperature control system, the requirements concerning the internal temperature control system in the thermal humidity profile defined in Figure 9 and Table 18 shall be omitted.

NOTE 1 It is valuable to measure relevant signals of the DUT during the complete test as well as after recovery. A deviation by more than ±5 % from the typical value of the DUT at the same temperature but without humidity load is considered large. Short events, for example with durations ≥1 ms, are detectable only with an adequately high sampling rate. Currents can be included in the monitoring, for example monitor the supply to the complete system under test.



Key

X time

Y1 temperature [°C]

Y2 relative humidity [%]

t_c one cycle

t_1,t_2,t_3,t_4,t_5 time parameter between steps (in accordance with Table 18)

1 to 8 step parameter (in accordance with Table 18)

——— chamber temperature

.... ITCS temperature

—·— relative humidity

(hatched) allowed tolerance for relative humidity

— — exemplary DUT temperature behaviour

Figure 9 — Temperature and humidity over time

NOTE 2 Humidity control below 10 °C is not feasible because of technical limits. Therefore, the relative humidity for T < 10 °C stays uncontrolled and is not specified.

Table 18 — Temperature and humidity over time

Parameter	Duration	Step	Description
t_1	As agreed	1	Climate chamber, DUT and ITCS are at a room temperature of (25 ± 2) °C. The climate chamber is at (95 ± 3) % relative humidity. Climate chamber temperature shall be set to (60 ± 2) °C with a gradient +35 K/h.
		2	After climate chamber temperature has reached (60 ± 2) °C, ITCS temperature shall be set to (40 ± 2) °C.
t_2	120 min	3, 8	After DUT temperature has reached (40 ± 2) °C: climate chamber temperature shall be set to (40 ± 2) °C with a gradient of −60 K/h.

Table 18 *(continued)*

Parameter	Duration	Step	Description
t_3	600 min	4	ITCS temperature shall be set to (20 ± 2) °C. Climate chamber temperature shall be set to (−10 ± 2) °C with a gradient of −5 K/h.
t_4	Until acclimatization of DUT according to step 6, but limited to 240 min	5	After DUT temperature has reached (20 ± 2) °C: The ITCS shall be turned off. ITCS temperature shall be uncontrolled.
t_5	Until acclimatization of DUT according to step 8, but limited to 480 min	6	After DUT temperature has reached (−7 ± 2) °C: Climate chamber temperature shall be set to (60 ± 2) °C with a gradient +35 K/h.
		7	After climate chamber temperature has reached (60 ± 2) °C, ITCS temperature shall be set to (40 ± 2) °C.

The mounting position of the DUT shall reflect the actual vehicle installation conditions.

A short functional check should be made in the time step t_2, for example by change to operating mode 6.2 for 10 min. Functional tests in t_3 and t_4 may also be performed.

A technical tightness check of the DUT defined in 7.2.1 should be performed before and after the test.

If the DUT is equipped with an internal temperature control system, then a leak tightness check of the internal temperature control system defined in 7.2.2 shall be performed before and after the test. If the internal temperature control system can be physically accessed only in a destructive procedure for the DUT, the tightness check of 7.2.2 may be omitted before the test.

8.7.3 Requirements

Breakage shall not occur. Functional status shall be class A as defined in ISO 19453-1.

There shall be no performance impairment caused by corrosion marks, infiltrations and impact on sealing function if applicable, visible markings and labelling or contamination including electro-migration and electro-chemical migration.

After the test, a water tightness check as defined in 7.2.1 shall be passed.

If the DUT has an internal temperature control system, a leak tightness check of the internal temperature control system as defined in 7.2.2 shall be passed after the test.

If the test is performed in a test sequence, check for migration can be performed at the end of the sequence.

8.8 Damp heat, steady state test

8.8.1 Purpose

The purpose of this test is to verify the resistance of battery pack or system against humid condition.

8.8.2 Test

The test should be performed with operating mode 6.1 instead of 2.1 and operating mode 7.1 instead of 3.2 according to damp heat steady state test as defined in ISO 19453-4, if the failure modes of this test are not covered by prequalification of the electronic sub-components (e.g. ECU).

8.8.3 Requirement

The requirement as defined in ISO 19453-4 shall be met.

8.9 Corrosion

8.9.1 General

For corrosion, building of local elements within a battery pack or system due to its active elements shall be considered. The chemical reaction depends on the electrochemical potential difference determined by both the material specific chemical potentials as well as the electrostatic potentials of the elements in contact.

NOTE 1 Intermediate non-destructive inspections and functional checks that are non-impairing to the remaining test time for the corrosion progression can be performed.

NOTE 2 Depending on the polarity of the voltage difference in the local elements the redox reaction leading to corrosion can even be reversed compared with the expected reaction direction from the electropotential series.

8.9.2 Mixed gas corrosion

8.9.2.1 Purpose

This test simulates the use of the DUT in the presence of corrosive gases, for example in highly polluted atmospheres.

Failure mode is an electrical malfunction caused by insulating corrosion products on the surface of electrical contacts. This test is relevant for, for example SMD components, LEDs, plug contacts and open switching contacts. Another failure mode is the penetration of protective coatings (e.g. paint) with subsequent corrosion of the structures underneath.

8.9.2.2 Test

Perform the test as defined in IEC 60068-2-60, Test Ke, method 4.

The operating mode of the DUT shall be 5.2.

The test duration is:

— 10 days for a battery pack or system intended for mounting in the passenger compartment or luggage/load compartment;

— 21 days for all other mounting locations.

Component tests for all components of the battery pack or system exposed to a gaseous atmosphere may be performed in case a severity comparable to system level is assured.

Alternatively, the test can be performed with a dummy DUT, for example without battery cells. The dummy DUT shall have same enclosure and same interfaces (e.g. connectors, service-cover) like a fully functional battery pack or system and equivalent mass distribution inside the battery pack.

8.9.2.3 Requirements

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

There shall be no performance impairment caused by corrosion marks, infiltrations and impact on sealing function if applicable, visible markings and labelling or contamination including electro-migration and electro-chemical migration.

If the test is performed in a test sequence and the check for migration can only be performed with a physical destructive procedure for the DUT, the analysis may be performed at the end of the sequence.

8.9.3 Salt-spray test for external mounting location

8.9.3.1 General

The salt-spray cyclic test shall only be applied to a battery pack or system with an external mounting locating in the vehicle. The degrees of protection of the DUT enclosure (IP code in accordance with ISO 20653) shall be considered, if the test is applicable or not.

This test is focused on different material compositions and components including sealings and throughputs. Alternatively, corrosion tests in accordance with ISO 19453-4 can be used.

8.9.3.2 Test

It shall be agreed between customer and supplier whether the test shall be performed on a fully functional battery pack or system or on a dummy DUT, for example without battery cells. The dummy DUT shall have same enclosure and same interfaces (e.g. connectors, service-cover) like a fully functional battery pack or system and equivalent mass distribution inside the battery pack.

The DUT shall be fitted in the as-installed position.

Equipotential bonding shall be connected to the DUT as defined by interface definition and as installed in the vehicle. The material pairing shall be the same as the one used in the vehicle mounting.

If a real battery pack or system is used for the test, operating mode 6.1 shall apply. Every 7 days, operating mode 7.1 shall apply for 5 min (−0 min, +1 min), due to status documentation and requirement check.

It shall be agreed between customer and supplier whether a hose can be used or not in order to connect the inside of the battery pack or system with an additional pressure compensation device placed outside of the corrosion test chamber and thus enable venting in case of obstruction of pressure compensation device(s) of the traction battery system due to salt.

Duration of test shall be 6 test cycles according to the cycle description below. 6 × (5 days corrosion test + 2 days environmental cycle test) = 42 days.

If the specified limits in this test exceed T_{min} or T_{max} the lower and upper boundary temperatures shall be adjusted to T_{min} or T_{max}.

This test shall be performed in a climatic chamber as per ISO 9227 set up for a corrosion cycle test.

Perform the first test part over 5 days. The test sequence for each day is specified below:

— 4 h salt spray test, test method NSS as per ISO 9227 with modified testing solution;

— 4 h cooling-off phase at room temperature (18 °C to 28 °C) and (40 % to 60 %) relative humidity;

— 16 h damp heat aging, test atmosphere CH (condensation atmosphere with constant high humidity) as per ISO 6270-2.

Then, age the DUT for two days in an environmental cycle test under the following test conditions:

— limit temperatures: (+80 ± 2) °C and (−40 ± 2) °C;

— holding time at limit temperature: 4 h;

— heating and cooling-off time: 2 h;

— relative humidity at 80 °C: (80 ± 3) %.

One test cycle takes one week to complete.

A modified testing solution shall be used for the salt spray test. A testing solution as per ISO 9227 can also be used. The modified testing solution is prepared from analytically pure table salt (NaCl, purity grade as per German Pharmacopoeia DAB 7 or equivalent regional/national standard), calcium chloride ($CaCl_2$, anhydrous, medium grained, pure), and deionized or distilled water (conductivity ≤2 mS/m at (23 ± 2) °C). 40 g of NaCI and 10 g of $CaCl_2$ per litre of water are used to prepare the testing solution. The pH value of the collected condensate shall be between 6,5 and 7,2. It may be necessary to add diluted hydrochloric acid to obtain the specified pH value. Electrometrical measurement at (25 ± 2) °C with a glass electrode may be used.

NOTE 1 Loading of the DUT with the saline reagent in the test chamber does not fully reproduce the loading present in field use. A battery pack or system mounted to the exterior vehicle underbody is likely to be exposed mainly from underneath with saline spray, while in the test chamber the exposure occurs mainly from above. For this mounting location, it is beneficial to choose a test procedure agreed between customer and supplier that ensures wetting of all DUT areas that are also exposed in field usage.

NOTE 2 The mass loss of test coupons (metal plates) in salt spray tests is different according to the kind of used materials. Correlation between tests can be performed by using test pieces of coupons. See ISO 14993:2018, Annex B for the essential information.

8.9.3.3 Requirements

After the test, the test for equipotential bonding defined in 7.1.2 shall be passed.

After the test, a technical tightness check of the battery pack or system defined in 7.2.1 shall be passed.

If the DUT has an internal temperature control system, the leak tightness check of the internal temperature control system defined in 7.2.2 shall be passed after the test.

There shall be no performance impairment caused by corrosion marks, infiltrations and impact on sealing function if applicable, visible markings and labelling or contamination including electro-migration and electro-chemical migration.

NOTE An example of a corrosive infiltration criterion is given in Annex E.

8.9.4 Salt corrosion test for internal mounting location

8.9.4.1 General

The salt corrosion test shall be applied to a battery pack or system with a mounting locating in the area close to the footwell or in the luggage/load compartment of the vehicle.

Application of the test depends on system architecture and shall be agreed between customer and supplier.

Operating mode 5.1 shall be used. Protective caps for the electrical joints and interconnections shall be present.

8.9.4.2 Test

Perform 28 thermal humidity cycles in conjunction with corrosive conditioning of the DUT as shown in Figure 10 with the environmental profile of Figure 11 and Table 19. Transition times between the different test environments of time step t_1 and t_2 shall be as short as possible. A two-chamber system may be used.

For conditioning, the DUT shall be sprayed with salt solution from every direction, excluding the supportive surface. The salt solution shall be distributed as homogenous sprinkles across the DUT surface. The solution shall be prepared as defined in ISO 9227 and diluted from 5 % (50 g/l) to 0,5 %.

Short interruptions between fully completed 24 h thermal humidity cycles in Figure 10 are permitted with climatic conditions of the t_1 phase, for example over weekends.

Distinction in the test severity shall be made with respect to the DUT mounting location within the vehicle by applying a different concentration of the salt solution and a different number of conditioning cycles.

8.9.4.2.1 Severity 1 — Interior protected mounting location

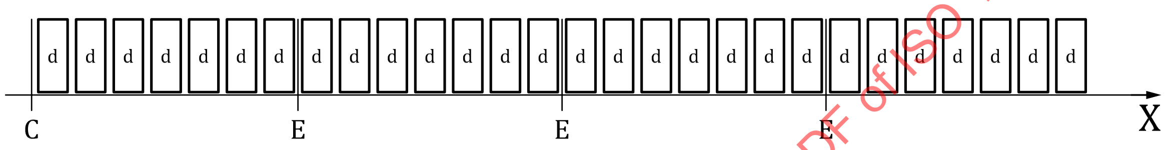
This condition simulates salinity of coastal air for protected mounting locations, for example in the trunk or passenger compartment of the vehicle.

Conditioning of the DUT shall be performed with a salt solution of 0,5 % salinity once before the first cycle as shown in Figure 10.

8.9.4.2.2 Severity 2 — Interior unprotected mounting location

This condition simulates salt contamination for unprotected mounting locations, for example in the area of the foot well or underneath passenger seats.

Conditioning of the DUT shall be performed with a salt solution of 5 % salinity once before the first cycle and after the 7th, 14th and 21st cycle as shown in Figure 10.



Key

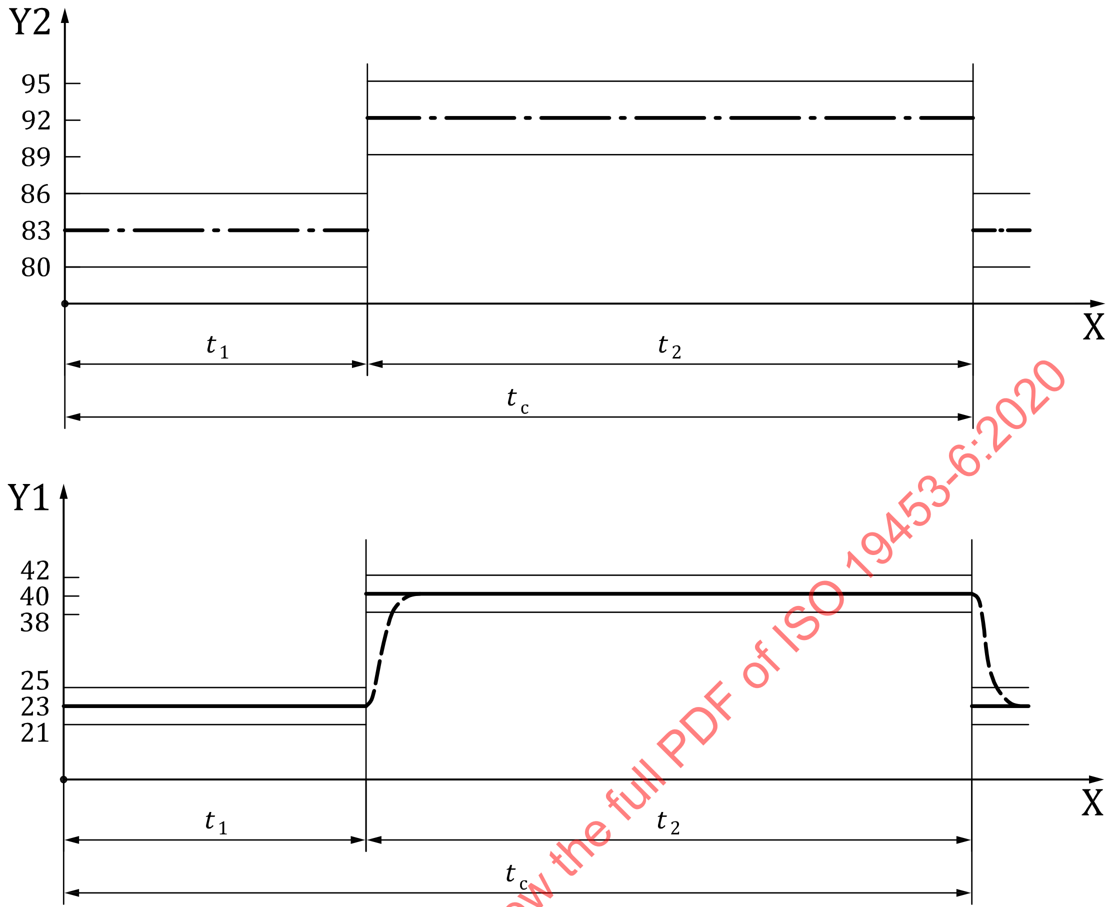
X time

d 24 h thermal humidity cycle as defined in Figure 11 and Table 19

C initial conditioning of the DUT with salt solution

E additional conditioning of the DUT with salt solution for test with severity 2

Figure 10 — Salt corrosion test sequence



Key

X time

Y1 temperature [°C]

Y2 relative humidity [%]

t_c one 24 h cycle

t_1, t_2 time parameter (in accordance with Table 19)

——— chamber temperature

—·—·— relative humidity

———— specification limits

— — — exemplary DUT temperature behaviour

Figure 11 — Humidity and temperature over time

Table 19 — Humidity and temperature over time

Parameter	Duration [h]	Temperature [°C]	Relative humidity [%]
t_1	8	23 ± 2	83 ± 3
t_2	16	40 ± 2	92 ± 3

8.9.4.3 Requirements

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

There shall be no performance impairment caused by corrosion marks, infiltrations and impact on sealing function if applicable, visible markings and labelling or contamination including electro-migration and electro-chemical migration.

8.10 Chemical resistance

Perform the chemical resistance test as defined in ISO 19453-5.

Test conditions may be applied to components of the battery pack or system.

Annex A
(informative)

Example of leak tightness check

A.1 Example 1

The leak tightness check of the DUT's internal temperature control system can be performed with a 100 % helium leak tightness tester.

At first, a low-pressure test with 30 kPa should be performed, followed by high-pressure test with 250 kPa and a normalised flow rate at nominal pressure of 0,6 cm^3/min.

In the low-pressure test, the pressure raise in 30 s should not be more than 0,5 kPa. In the over pressure test not more than 3 cm^3/min should be required to hold 250 kPa of pressure in the system. Tolerance of setting pressure should be agreed between customer and supplier.

A.2 Example 2

For the leak test, the pressure gradient that prevails in the practical use of the specimen should be simulated.

A method is conceivable, in which the specimen is evacuated and connected to a detector and then placed in a chamber containing tracer gas or immersed completely in tracer gas. Alternatively, suspected points on the DUT can be sprayed with the tracer gas. A method is conceivable as well, in which the interior of the DUT is loaded with the tracer gas and an enclosing test chamber is connected to the leak detector.