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Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems —

Part 4: Performance testing

Véhicules routiers à propulsion électrique — Spécifications d'essai pour packs et systèmes de batterie de traction aux ions lithium —

Partie 4: Essais de performance

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Foreword

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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. www.iso.org/directives

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 37, *Electrically propelled vehicles*.

This document cancels and replaces ISO 12405-1:2011 and ISO 12405-2:2012 by summarizing the test specifications.

Introduction

Lithium-ion-based battery systems are an efficient alternative energy storage system for electrically propelled vehicles. The requirements for lithium-ion based battery systems for use as a power source for the propulsion of electric road vehicles are significantly different from those batteries used for consumer electronics or stationary usage.

This document provides specific test procedures for lithium-ion battery packs and systems specially developed for propulsion of road vehicles. This document specifies such tests and related requirements to ensure that a battery pack or system is able to meet the specific needs of the automobile industry. It enables vehicle manufactures to choose test procedures to evaluate the characteristics of a battery pack or system for their specific requirements.

ISO 12405 specifies test procedures for lithium-ion battery packs and systems which are connected to the electric propulsion system of electrically propelled vehicles.

The objective of ISO 12405 is to specify standard test procedures for the basic characteristics of performance, reliability and electrical functionality of lithium-ion battery packs and systems and to assist the user in comparing the test results achieved for different battery packs or systems.

NOTE 1 The general safety relevant tests and requirements are given in ISO 6469-1[1)].

NOTE 2 Environmental conditions and testing will be given in the future ISO 19453-6[2)].

For specifications for battery cells, see IEC 62660-1 to 3.

1) Under preparation. Stage at the time of publication: ISO/DIS 6469-1.

2) Under preparation. Stage at the time of publication: ISO/CD 19453-6.

Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems —

Part 4:
Performance testing

1 Scope

This document specifies test procedures for the basic characteristics of performance, reliability and electrical functionality for the battery packs and systems for either high-power or high-energy application. Unless otherwise stated, the test applies to both applications.

NOTE 1 Typical applications for high-power battery packs and systems are hybrid electric vehicles (HEVs) and some type of fuel cell vehicles (FCVs).

NOTE 2 Typical applications for high-energy battery packs and systems are battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and some type of fuel cell vehicles (FCVs).

NOTE 3 Testing on cell level is specified in IEC 62660 series.

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 6469-1[3)], *Electrically propelled road vehicles — Safety specifications — Part 1: On-board rechargeable energy storage system (RESS)*

ISO 6469-3[4)], *Electrically propelled road vehicles — Safety specifications — Part 3: Protection of persons against electric shock*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

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

3.1
battery control unit
BCU
electronic device that controls, manages, detects or calculates electric and thermal functions of the *battery system* (3.3) and that provides communication between the battery system and other vehicle controllers

Note 1 to entry: See A.3.1 for further explanations.

3) Under preparation. Stage at the time of publication: ISO/DIS 6469-1.

4) Under preparation. Stage at the time of publication: ISO/DIS 6469-3.

3.2
battery pack
energy storage device that includes cells or cell assemblies normally connected with *cell electronics* (3.5), power supply circuits and overcurrent shut-off device, including electrical interconnections, interfaces for external systems

Note 1 to entry: See A.2 for further explanations.

Note 2 to entry: Examples of external systems are cooling, voltage class B, auxiliary voltage class A and communication.

3.3
battery system
energy storage device that includes cells or cell assemblies or *battery pack*(s) (3.2) as well as electrical circuits and electronics

Note 1 to entry: See A.3.2 and A.3.3 for further explanations. Battery system components can also be distributed in different devices within the vehicle.

Note 2 to entry: Examples of electronics are the BCU and contactors.

3.4
capacity
total number of ampere hours that can be withdrawn from a fully charged *battery pack* (3.2) under specified conditions

3.5
cell electronics
electronic device that collects and possibly monitors thermal or electric data of cells or cell assemblies and contains electronics for cell balancing, if necessary

Note 1 to entry: The cell electronics can include a cell controller. The functionality of cell balancing can be controlled by the cell electronics or by the BCU.

3.6
customer
party that is interested in using the battery pack or system and therefore orders or performs the test

EXAMPLE A vehicle manufacturer.

3.7
device under test
DUT
battery pack or battery system

3.8
electric drive
combination of a traction motor, power electronics and their associated controls for the conversion of electric to mechanical power and vice versa

3.9
electrically propelled vehicle
vehicle with one or more *electric drive*(s) (3.8) for vehicle propulsion

3.10
energy density
amount of stored energy related to the *battery pack* (3.2) or *system* (3.3) volume

Note 1 to entry: The battery pack or system includes the cooling system, if any, to the point of a reversible attachment of the coolant lines or air ducts, respectively.

Note 2 to entry: Energy density is expressed in watt hours per litre (Wh/l).

3.11
energy round trip efficiency
ratio of the net d.c. energy delivered by a DUT during a discharge test to the total d.c. energy required to restore the initial SOC by a standard charge

Note 1 to entry: The net d.c. energy is expressed as watt hours (Wh) discharge and the total d.c. energy is expressed as watt hours (Wh) charge.

3.12
high-energy battery pack and system
battery pack (3.2) and *system* (3.3) using cells, which have the numerical ratio between maximum allowed electric power output and electric energy output at a 1C discharge rate at RT lower than 10

Note 1 to entry: Typically high-energy battery packs and systems are designed for applications in BEVs and PHEVs.

Note 2 to entry: The allowed electric power output is expressed as power in watts (W) and the electric energy output is expressed as energy in watt hours (Wh).

3.13
high-power battery pack and system
battery pack (3.2) and *system* (3.3) using cells, for which the numerical ratio between maximum allowed electric power output and electric energy output at a 1C discharge rate at RT equal to or higher than 10

Note 1 to entry: Typically high-power battery packs and systems are designed for applications in HEVs and FCVs.

Note 2 to entry: The allowed electric power output is expressed as power in watts (W) and the electric energy output is expressed as energy in watt hours (Wh).

3.14
maximum working voltage
highest value of a.c. voltage (rms) or of d.c. voltage which may occur in an electric system under any normal operating conditions according to the supplier's specifications, disregarding transients

3.15
overcurrent protection
protection intended to operate when the current is in excess of a predetermined value

3.16
rated capacity
supplier's specification of the total number of ampere hours that can be withdrawn from a fully charged battery pack or system for a specified set of test conditions such as discharge rate, temperature and discharge cut-off voltage

3.17
room temperature
RT
temperature of (25 ± 2) °C

3.18
sign of battery current
discharge current is specified as positive and the charge current as negative

3.19
specific energy
amount of stored energy related to the *battery pack* (3.2) or *system* (3.3) mass

Note 1 to entry: The mass of battery pack or system includes the mass of the temperature conditioning system if any up to the point of a reversible attachment of the coolant lines or air ducts and the coolant mass.

Note 2 to entry: Specific energy is expressed in watt hours per kilogram (Wh/kg).

3.20
state of charge
SOC
available capacity in a battery pack or system expressed as a percentage of *rated capacity* (3.15)

3.21
top off charge
additional charge which eliminates possible SOC reduction after SCH at RT followed by thermal equilibration at a different temperature

3.22
supplier
party that provides battery systems and packs

EXAMPLE A battery manufacturer.

3.23
voltage class A
classification of an electric component or circuit with a *maximum working voltage* (3.14) of ≤30 V a.c. (rms) or ≤60 V d.c., respectively

Note 1 to entry: See ISO 6469-3.

3.24
voltage class B
classification of an electric component or circuit with a *maximum working voltage* (3.14) of (>30 and ≤1 000) V a.c. (rms) or (>60 and ≤1 500) V d.c., respectively

Note 1 to entry: See ISO 6469-3.

4 Symbols and abbreviated terms

4.1 Symbols

C_{fade}	Capacity fade
$C_{rt,t0}$	Rated 1 C capacity at BOL
$I_{c,max}$	maximum continuous charge current specified by the supplier for energy efficiency at fast charging testing
$I_{d,max}$	maximum continuous discharge current specified by the supplier for energy and capacity testing
$I_{dp,max}$	maximum discharge pulse current specified by the supplier for power, internal resistance and energy efficiency testing
T_{max}	maximum temperature
T_{min}	minimum temperature
T	Time

4.2 Abbreviated terms

a.c.	alternating current
BCU	battery control unit
BEV	battery electric vehicle
BOL	beginning of life
C	capacity, expressed in ampere hours (Ah)
nC	current rate equal to n times the one hour discharge capacity expressed in ampere (e.g. 3C is equal to three times the 1 h current discharge rate, expressed in ampere)
d.c.	direct current
DUT	device under test
EODV	End-of-discharge-voltage
EUCAR	European Council for Automotive Research
FCV	fuel cell vehicle
HEV	hybrid electric vehicle
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
Li	lithium
Li-ion	lithium-ion
OCV	Open Circuit Voltage
PHEV	plug-in hybrid electric vehicle
PSD	power spectral density
RESS	rechargeable energy storage system
rms	root mean square
RT	room temperature (25 ± 2) °C
SC	standard cycle
SCH	standard charge
SDCH	standard discharge
SOC	state of charge
USABC	United States Advanced Battery Consortium

5 General requirements

5.1 General conditions

5.1.1 Prerequisites

A battery pack or system to be tested according to this document shall fulfil the following requirements:

— The electrical safety design and safety requirements shall comply with the requirements given in ISO 6469-1[5]) and ISO 6469-3[6]).

— The necessary documentation for operation and needed interface parts for connection to the test equipment (i.e. connectors, plugs including cooling, communication) shall be delivered together with the DUT.

A battery system shall enable the specified tests, i.e. via specified test modes implemented in the BCU, and shall be able to communicate with the test bench via common communication buses.

The battery pack subsystem as a DUT shall comprise all parts specified by the customer (e.g. including mechanical and electrical connecting points for mechanical test).

If not otherwise specified, before each test the DUT shall be equilibrated at the test temperature. The thermal equilibration is reached if during a period of 1 h without active cooling the deviations between test temperature and temperature of all cell temperature measuring points are lower than ±2 K.

If not otherwise specified, each charge and each SOC change shall be followed by a rest period of 30 min.

5.1.2 Accuracy of measurement equipment and measured values

The accuracy of external measurement equipment shall be at least within the following tolerances:

— voltage ±0,5 %

— current ±0,5 %

— temperature ±1 K

The overall accuracy of externally controlled or measured values, relative to the specified or actual values, shall be at least within the following tolerances:

— voltage ±1 %

— current ±1 %

— temperature ±2 K

— time ±0,1 %

— mass ±0,1 %

— dimensions ±0,1 %

All values (time, temperature, current and voltage) shall be noted at least every 5 % of the estimated discharge and charge time, except if it is noted otherwise in the individual test procedure.

5) Under preparation. Stage at the time of publication: ISO/DIS 6469-1.

6) Under preparation. Stage at the time of publication: ISO/DIS 6469-3.

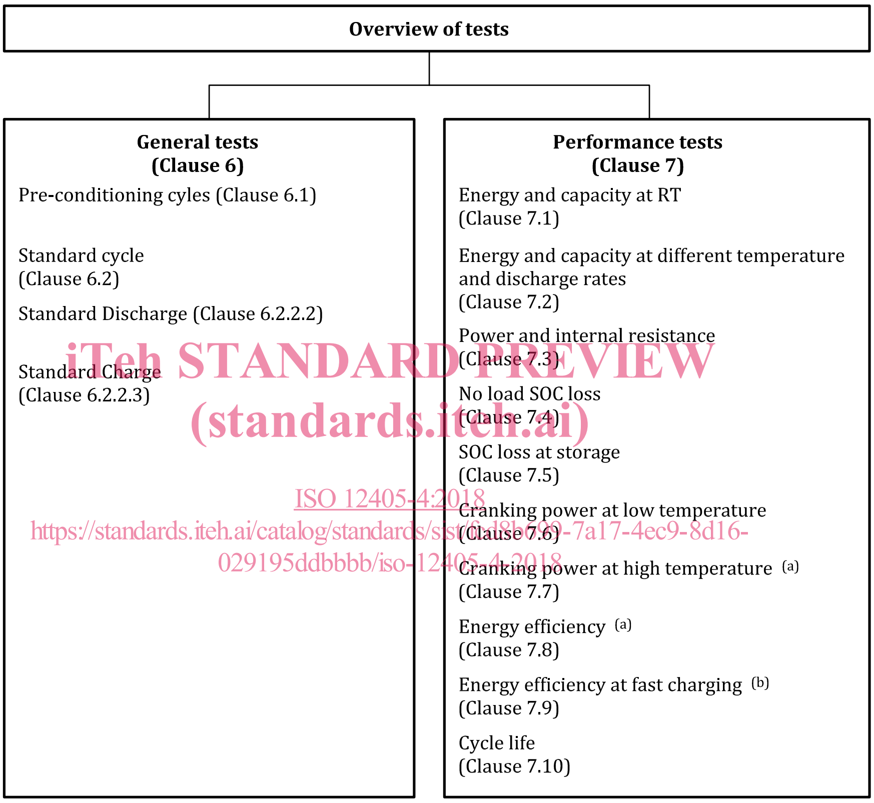
5.2 Test sequence plan

The test sequence for an individual battery pack or system, or a battery pack subsystem shall be based on agreement between the customer and supplier with consideration of tests in 5.3.

An example for a list of test conditions to be agreed between customer and supplier is provided in Table C.1 for high-power battery packs and systems or in Table C.2 for high-energy battery packs and systems.

5.3 Tests

An overview of the tests is given in Figure 1 where the references to the specific subclauses are also given. Annex B provides examples for collection of test data.



Key

a The test applies only to high-power battery packs and systems.

b The test applies only to high-energy battery packs and systems.

Figure 1 — Test sequence

5.4 Preparation of battery pack and system for bench testing

5.4.1 Preparation of battery pack

If not otherwise specified, the battery pack shall be connected with voltage class B if any, and voltage class A connections to the test bench equipment. Contactors, available voltage, current and temperature data shall be controlled according to the supplier’s requirements and according to the given test specification by the test bench equipment. The passive overcurrent protection shall be operational in the battery pack. Active overcurrent protection shall be maintained by the test bench equipment, if necessary, via disconnection of the battery pack main contactors. The cooling device may be connected to the test bench equipment and operated according to the supplier's requirements.

5.4.2 Preparation of battery system

If not otherwise specified, the battery system shall be connected with voltage class B, if any, and voltage class A and cooling connections to the test bench equipment. The battery system shall be controlled by the BCU, the test bench equipment shall follow the operational limits provided by the BCU via bus communication. The test bench equipment shall maintain the on/off requirements for the main contactors and the voltage, current and temperature profiles according to the requested requirements of the given test procedure. The battery system cooling device and the corresponding cooling loop at the test bench equipment shall be operational according to the controls by the BCU, unless otherwise specified in the given test procedure. The BCU shall enable the test bench equipment to perform the requested test procedure within the battery system operational limits. If necessary, the BCU program shall be adapted by the supplier for the requested test procedure. The active and passive overcurrent protection shall be operational by the battery system. Active overcurrent protection shall be maintained by the test bench equipment, too, if necessary via request of disconnection of the battery system main contactors.

6 General tests

6.1 Preconditioning cycles

6.1.1 Purpose

The DUT shall be conditioned by performing some electrical cycles, before starting the real testing sequence, in order to ensure an adequate stabilization of the battery pack or system performance.

This test applies to battery packs and systems.

6.1.2 Test procedures

6.1.2.1 High-power battery pack and system

For high-power battery packs and systems the procedure shall be the following:

— The test shall be performed at RT.

— The discharges shall be performed at 2 C or at a different current if suggested and/or used by the supplier in testing before delivery. The charging shall be performed according to the recommendations of the supplier.

— Five consecutive preconditioning cycles shall be performed. Fewer cycles may be agreed between the customer and supplier.

— At the end of discharge, the battery pack or system voltage shall not go below the minimum voltage recommended by the supplier.

— The battery pack or system shall be considered “preconditioned” if the discharged capacity during two consecutive discharges does not change by a value greater than 3 % of the rated capacity (30 min discharge or other discharge process adopted during test according to supplier indications). If the discharge process is equal to that used by the supplier on the same battery pack or system during factory tests, the data from the second cycle may be compared directly with the data from the supplier.

— If the precondition requirements cannot be fulfilled, the customer and supplier shall agree on further procedure.

NOTE The discharge rate of 2 C is used in order to shorten the preconditioning.

6.1.2.2 High-energy battery pack and system

For high-energy battery packs and systems the procedure shall be the following:

— The test shall be performed at RT.

— The discharges shall be performed at C/3 or at a different current if suggested and/or used by the supplier in testing before delivery. The charging shall be performed according to the recommendations of the supplier.

— Three consecutive preconditioning cycles shall be performed. If agreed between customer and supplier, only two cycles shall be performed.

— At end of discharge, the battery pack or system voltage shall not go below the minimum voltage recommended by the supplier (the minimum voltage is the lowest voltage under discharge without irreversible damage).

— The battery pack or system shall be considered as “preconditioned” if the discharged capacity during two consecutive discharges does not change by a value greater than 3 % of the rated capacity. If the discharge process is equal to that used by the supplier on the same battery pack or system during factory tests, the data from the second cycle can be compared directly with the data from the supplier.

— If the preconditioning requirements cannot be fulfilled, customer and supplier shall agree on further procedure.

6.2 Standard Cycle (SC)

6.2.1 Purpose

The purpose of the standard cycle (SC) is to ensure the same initial condition for each test of a battery pack or system. A standard cycle (SC), as described below, shall be performed prior to each test.

This test applies to battery packs and systems.

6.2.2 Test procedures

6.2.2.1 General

The standard cycle (SC) shall be performed at RT. The SC shall comprise a standard discharge (SDCH), see 6.2.2.2, followed by a standard charge (SCH), see 6.2.2.3.

If, for any reason, the time interval between the end of the SC and the start of a new test is longer than 3 h, the SC shall be repeated.

6.2.2.2 Standard discharge (SDCH)

6.2.2.2.1 High-power battery pack and system

Discharge rate:

— 1 C or other specific discharge rate according to the specifications given by the supplier.

Discharge limit:

— According to the specifications given by the supplier.

Rest period after discharge to reach a stable condition:

— 30 min or a thermal equilibration at RT of the DUT is reached.