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ISO 12405-2

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

Part 2: High-energy applications

Véhicules routiers à propulsion électrique — Spécifications d'essai pour des installations de batterie de traction aux ions lithium —

Partie 2: Applications à haute énergie

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 12405-2 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 21, *Electrically propelled road vehicles*.

ISO 12405 consists of the following parts, under the general title *Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems*:

— *Part 1: High-power applications*

— *Part 2: High-energy applications*

The following part is under preparation:

— *Part 3: Safety performance requirements*

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 to be used as a power source for the propulsion of electric road vehicles are significantly different from those for batteries used for consumer electronics or stationary usage.

ISO 12405 provides specific test procedures for lithium-ion battery packs and systems specially developed for propulsion of road vehicles. It 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 manufacturers to choose test procedures to evaluate the characteristics of a battery pack or system for their specific requirements.

A coordination of test specifications for battery cells, packs and systems for automotive application is necessary for practical usage of standards.

Specifications for battery cells are given in IEC 62660-1 and IEC 62660-2.

Some tests as prescribed within this specification are based on existing specifications: *USABC, EUCAR, FreedomCar* and other sources.

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

Part 2: High-energy applications

1 Scope

ISO 12405 specifies test procedures for lithium-ion battery packs and systems to be used in electrically propelled road vehicles.

The specified test procedures enable the user of ISO 12405 to determine the essential characteristics of performance, reliability and abuse of lithium-ion battery packs and systems. They also assist the user in comparing the test results achieved for different battery packs or systems.

Therefore the objective of ISO 12405 is to specify standard test procedures for the basic characteristics of performance, reliability and abuse of lithium-ion battery packs and systems.

ISO 12405 enables the setting up of a dedicated test plan for an individual battery pack or system subject to an agreement between customer and supplier. If required, the relevant test procedures and/or test conditions of lithium-ion battery packs and systems can be selected from the standard tests provided in ISO 12405 to configure a dedicated test plan.

This part of ISO 12405 specifies the tests for high-energy battery packs and systems.

NOTE 1 Typical applications for high-energy battery packs and systems are battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV).

NOTE 2 Testing on cell level is specified in IEC 62660-1 and IEC 62660-2.

2 Normative references

The following referenced documents are indispensable for the application 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, *Electrically propelled road vehicles — Safety specifications — Part 1: On-board rechargeable energy storage system (RESS)*

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

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

ISO 16750-3, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 3: Mechanical loads*

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

IEC 60068-2-30, *Environmental testing — Part 2-30: Tests — Test Db: Damp heat, cyclic (12 h + 12 h cycle)*

IEC 60068-2-47, *Environmental testing — Part 2-47: Tests — Mounting of specimens for vibration, impact and similar dynamic tests*

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

3 Terms and definitions

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

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

NOTE See also 5.5.1 for further explanation.

3.2
battery pack
mechanical assembly comprising battery cells and retaining frames or trays, and possibly components for battery management

NOTE See 5.4 and A.2 for further explanation.

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

NOTE 1 See 5.5.2, 5.5.3, A.3.1 and A.3.2 for further explanation. Battery system components can also be distributed in different devices within the vehicle.

NOTE 2 Examples of electronics are the BCU and contactors.

3.4
capacity
total number of ampere hours that can be withdrawn from a battery under specified conditions

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

NOTE The cell electronics may include a cell controller. The functionality of cell balancing may be controlled by the cell electronics or it may be controlled 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 vehicle manufacturer

3.7
device under test
DUT
battery pack or battery system

3.8
energy density
amount of stored energy related to the battery pack or system volume

NOTE 1 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 Energy density is expressed in watt hours per litre (W·h/l).

3.9
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 The net d.c. energy is expressed as watt hours (W·h) discharge and the total d.c. energy is expressed as watt hours (W·h) charge.

3.10
high-energy application
characteristic of device or application, for which the numerical ratio between maximum allowed electric power output and electric energy output at a 1C discharge rate at RT for a battery pack or system is typically lower than 10

NOTE Typically high-energy battery packs and systems are designed for applications in BEVs.

NOTE 2 The allowed electric power output is expressed as power in watts (W) and the electric energy output is expressed as energy in watt hours (W·h).

3.11
high-power application
characteristic of device or application, for which the numerical ratio between maximum allowed electric power output and electric energy output at a 1C discharge rate at RT for a battery pack or system is typically equal to or higher than 10

NOTE 1 Typically high-power battery packs and systems are designed for applications in HEVs and FCVs.

NOTE 2 The allowed electric power output is expressed as power in watts (W) and the electric energy output is expressed as energy in watt hours (W·h).

3.12
maximum working voltage
highest value of a.c. voltage (r.m.s) or of d.c. voltage which may occur in an electric system under any normal operating conditions according to the manufacturer's specifications, disregarding transients

3.13
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

3.14
room temperature
RT
temperature of (25 ± 2) °C

3.15
sign of battery current
discharge current is specified as positive and the charge current as negative

3.16
specific energy
amount of stored energy related to the battery pack or system mass

NOTE 1 The battery pack or system shall include the cooling system, if any, to the point of a reversible attachment of the coolant lines or air ducts, respectively. For liquid cooled systems the coolant mass inside the battery pack or system shall be included.

NOTE 2 Specific energy is expressed in watt hours per kilogram (W·h/kg).

3.17
state of charge
SOC
available capacity in a battery pack or system

NOTE State of charge is expressed as a percentage of rated capacity.

3.18
standard charge (SCH) for top off
additional charge which eliminates possible SOC reduction after SCH at RT followed by thermal equilibration at a different temperature

3.19
supplier
party that provides battery systems and packs

EXAMPLE battery manufacturer

3.20
voltage class A
classification of an electric component or circuit with a maximum working voltage of $0 < U \leq 30$ V a.c. r.m.s. or $0 < U \leq 60$ V d.c.

NOTE For more details, see ISO 6469-3.

3.21
voltage class B
classification of an electric component or circuit with a maximum working voltage of $30 < U \leq 1\,000$ V a.c. r.m.s. or $60 < U \leq 1\,500$ V d.c.

NOTE For more details, see ISO 6469-3.

4 Symbols and abbreviated terms

a.c.	alternating current
BCU	battery control unit
BEV	battery electric vehicle
BOL	beginning of life
C	capacity, expressed in ampere hours (A·h)
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
EV	electric vehicle
FCV	fuel cell vehicle
HEV	hybrid electric vehicle

$I_{c,max}$	maximum continuous charge current specified by the manufacturer for energy efficiency at fast charging testing
$I_{d,max}$	maximum continuous discharge current specified by the manufacturer for energy and capacity testing
$I_{dp,max}$	maximum discharge pulse current specified by the manufacturer for power, internal resistance and energy efficiency testing
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
PNGV	partnership for a new generation of vehicles
PSD	power spectral density
RESS	rechargeable energy storage system
r.m.s.	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
η	efficiency

5 General requirements

5.1 General conditions

A battery pack or system to be tested according to this part of ISO 12405 shall fulfil the following requirements:

— The electrical safety design shall be approved according the requirements given in ISO 6469-1 and ISO 6469-3.

— 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.

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.

NOTE If agreed between customer and supplier, for a battery pack or system consisting of more than one subset the tests may be applied on such subsets.

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 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.

5.3 Tests

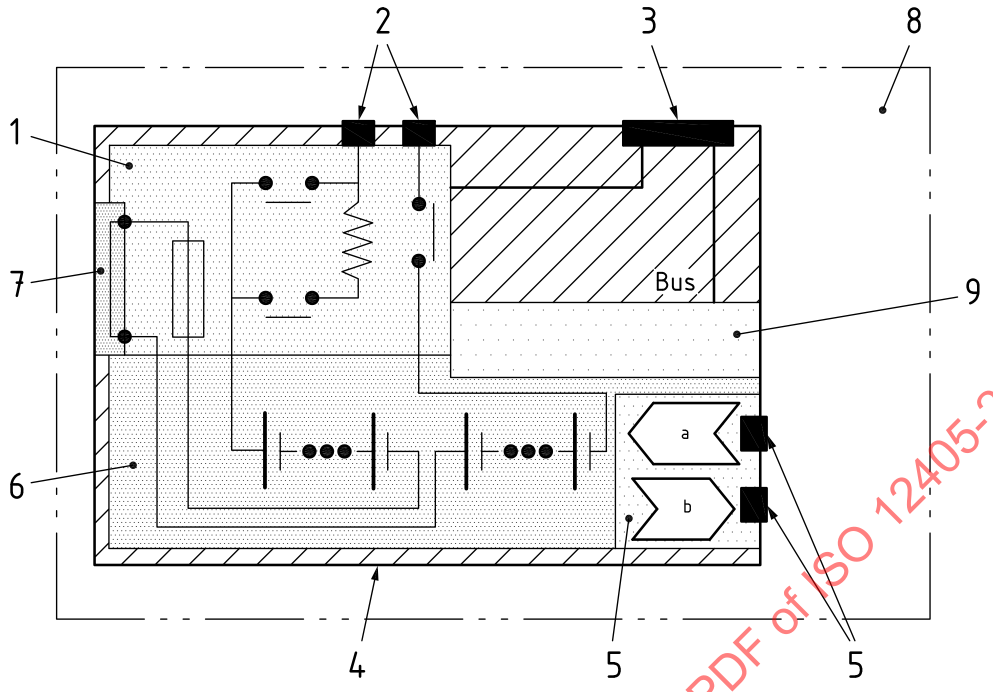
An overview about the tests is given in Figure 1, where the references to the specific clauses are also given.

Overview of tests

General tests (Clause 6)	Performance tests (Clause 7)	Reliability tests (Clause 8)	Abuse tests (Clause 9)
Pre-conditioning cycles (Clause 6.1)	Energy and capacity at RT (Clause 7.1)	Dewing (Clause 8.1)	Short circuit protection (Clause 9.2)
Standard cycle (Clause 6.2)	Energy and capacity at different temperature and discharge rates (Clause 7.2)	Thermal shock cycling (Clause 8.2)	Overcharge protection (Clause 9.3)
Standard discharge (Clause 6.2.2.2)	Power and internal resistance (Clause 7.3)	Vibration (Clause 8.3)	Overdischarge protection (Clause 9.4)
Standard charge (Clause 6.2.2.3)	Energy efficiency at fast charging (Clause 7.4)	Mechanical shock (Clause 8.4)	
	No load SOC loss (Clause 7.5)		
	SOC loss at storage (Clause 7.6)		
	Cycle life (Clause 7.7)		

Figure 1 — Test plan – overview

5.4 Battery pack - typical configuration



Key

1 voltage class B electric circuit (contactors, fuses, wiring)
2 voltage class B connections
3 voltage class A connections
4 normal use impact-resistant case
5 cooling device and connections
6 cell assembly
7 service disconnect
8 battery pack
9 cell electronics
a In.
b Out.

Figure 2 — Typical configuration of battery pack

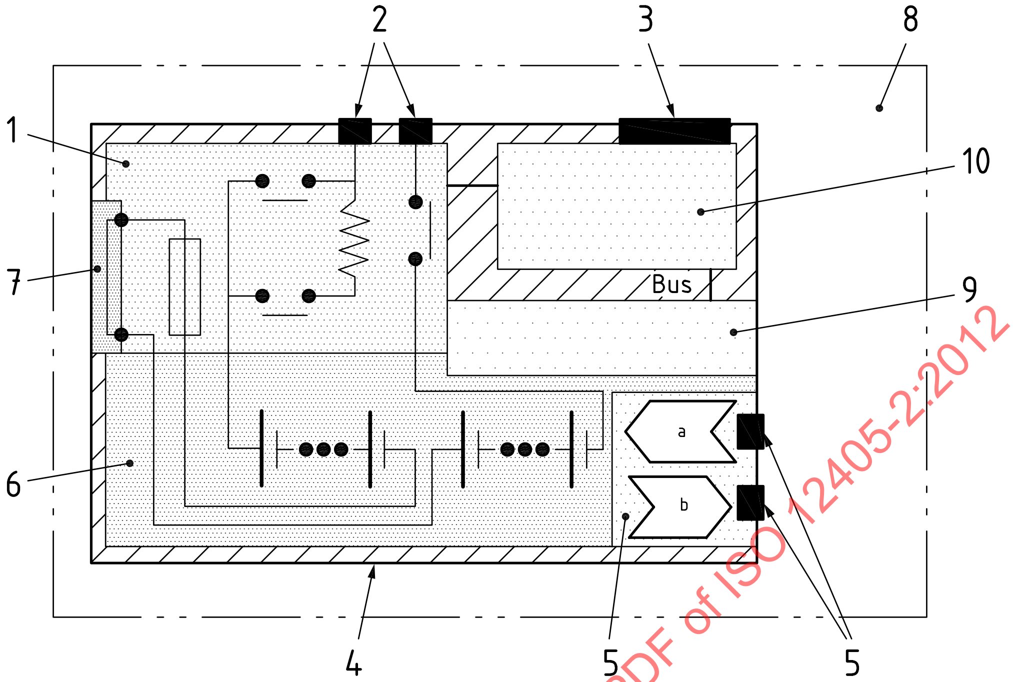
A battery pack represents an energy storage device that includes cells or cell assemblies, cell electronics, voltage class B circuit and overcurrent shut-off device including electrical interconnections, interfaces for cooling, voltage class B, auxiliary voltage class A and communication. The voltage class B circuit of the battery pack may include contactors. For a battery pack of 60 V d.c. or higher, a manual shut-off function (service disconnect) may be included. All components are typically placed in a normal use impact-resistant case.

5.5 Battery system - typical configuration

5.5.1 BCU

The BCU calculates state-of-charge and state-of-health and provides battery system operational limits to the vehicle management unit. The BCU may have direct access to the main contactors of the battery system in order to interrupt the voltage class B circuit under specified conditions, e.g. overcurrent, over voltage, low voltage, high temperature. The BCU may vary in design and implementation, it may be a single electronic unit integrated into the battery system or it may be placed outside the battery pack and connected via a communication bus or input/output lines to the battery pack. The BCU functionalities may be integrated functions of one or more vehicle control units.

5.5.2 Battery system with integrated battery control unit (BCU)



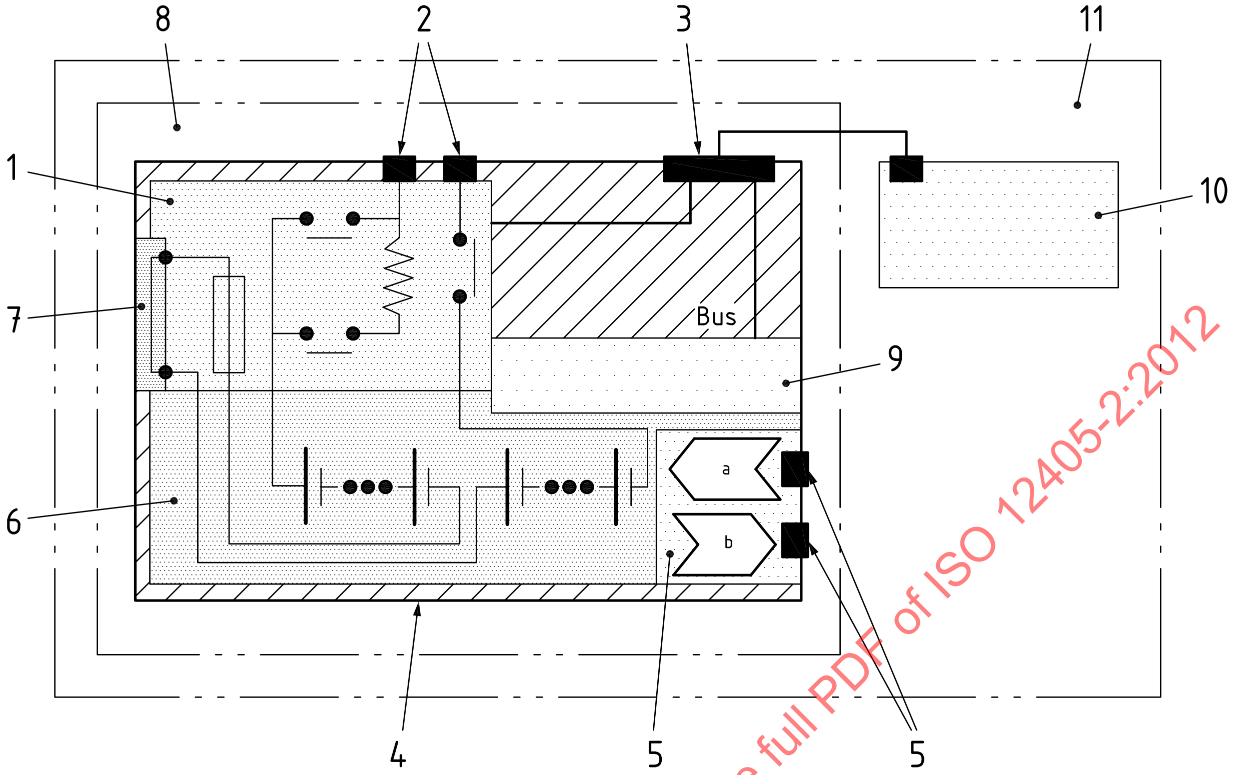
Key

1 voltage class B electric circuit (contactors, fuses, wiring)
2 voltage class B connections
3 voltage class A connections
4 normal use impact-resistant case
5 cooling device and connections
6 cell assembly
7 service disconnect
8 battery pack
9 cell electronics
10 battery control unit
a In.
b Out.

Figure 3 — Typical configuration of battery system with integrated BCU

A battery system represents an energy storage device that includes cells or cell assemblies, cell electronics, battery control unit, voltage class B circuit with contactors and overcurrent shut-off device including electrical interconnections, interfaces for cooling, voltage class B, auxiliary voltage class A and communication. For a battery system of 60 V d.c. or higher, a manual shut-off function (service disconnect) may be included. All components are typically placed in a normal use impact-resistant case. In this example, the battery control unit is integrated inside the normal use impact-resistant case and its control functionalities are connected to the battery pack.

5.5.3 Battery system with external battery control unit (BCU)



Key

1 voltage class B electric circuit (contactors, fuses, wiring)
2 voltage class B connections
3 voltage class A connections
4 normal use impact-resistant case
5 cooling device and connections
6 cell assembly
7 service disconnect
8 battery pack
9 cell electronics
10 battery control unit
11 battery system
a In.
b Out.

Figure 4 — Typical configuration of battery system with external BCU

A battery system represents an energy storage device that includes cells or cell assemblies, cell electronics, battery control unit, voltage class B circuit with contactors and overcurrent shut-off device including electrical interconnections, interfaces for cooling, voltage class B, auxiliary voltage class A and communication. For a battery system of 60 V d.c. or higher, a manual shut-off function (service disconnect) may be included. All components are typically placed in a normal use impact-resistant case. In this example, the battery control unit is placed outside the normal use impact-resistant case and its control functionalities are connected to the battery pack.

5.6 Preparation of battery pack and system for bench testing

5.6.1 Preparation of battery pack

If not otherwise specified, the battery pack shall be connected with voltage class B and voltage class A connections to the test bench equipment. Contactors, available voltage, current and temperature data shall be controlled according to the suppliers requirements and according to the given test specification by the test bench equipment. The passive overcurrent protection device 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.

5.6.1.1.1.1 Preparation of battery system

If not otherwise specified, the battery system shall be connected with voltage class B, 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 given test specifications and the controls by the BCU. 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 device 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 Pre-conditioning 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 procedure

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 regime 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 procedure

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)

Discharge rate:

— C/3 or other specific discharge regime 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.

6.2.2.3 Standard charge (SCH)

Charge procedure and end of charge criteria:

— C/3 or another specific charge regime according to the specifications given by the supplier. The specifications shall cover end of charge criteria and time limits for the overall charging procedure.

— In any case, the total charge procedure shall be completed within 8 h.

Rest period after charge to reach a stable voltage condition:

— 60 min.

7 Performance tests

7.1 Energy and capacity at RT

7.1.1 Purpose

This test measures DUT capacity in A·h at constant current discharge rates corresponding to the suppliers rated C/3 capacity in A·h (e.g., if the rated three hour discharge capacity is 45 A·h, the discharge rate is 15 A). The three hour rate (C/3) is used as reference for static capacity and energy measurement and as a standard rate for pack and system level testing. In addition, if applicable, the 1C, 2C and the maximum permitted C rate shall be performed for capacity determination to meet the high-energy system application requirements. Discharge is terminated on supplier specified discharge voltage limits depending on discharge rates.

This test applies to battery packs and systems.

7.1.2 Test procedure

The test shall be performed at RT with the discharge rates C/3, 1C, 2C (if 2C is less than $I_{d,max}$) and the maximum C rate as permitted by the supplier.

This test applies to battery packs and systems.

The test sequence shall be performed as specified in Table 1.

Table 1 — Test sequence energy and capacity test at RT

Step	Procedure	Ambient temperature
1.1	Thermal equilibration	RT
1.2	Standard charge (SCH)	RT
1.3	Standard cycle (SC)	RT
2.1	Discharge at C/3	RT
2.2	Standard charge (SCH)	RT
2.3	Discharge at 1C	RT
2.4	Standard charge (SCH)	RT
2.5	Discharge at 2C	RT
2.6	Standard charge (SCH)	RT
2.7	Discharge at $I_{d,max}$	RT
2.8	Standard charge (SCH)	RT
3.1	Standard cycle (SC)	RT

The standard charge (SCH) procedure shall follow 6.2.2.3.

The standard cycle (SC) procedure shall follow 6.2.

All discharge tests shall be terminated at the supplier's discharge voltage limits.

After discharge, the DUT shall rest at least for 30 min or shall be thermally equilibrated at the requested ambient temperature or a fixed time period shall be used to allow for thermal equilibration before starting the next step in the test sequence.

7.1.3 Requirement

If the C/3 capacity obtained during testing at 7.1.2 step no. 2.1 differs more than 5 % from the supplier's C/3 specification, this measured C/3 capacity shall be used as rated capacity and shall be the basis value for all further discharge current requirements, i.e. the value for C in each discharge current calculation nC shall be based on the measured C/3 capacity.

The following data shall be reported:

— current, voltage, DUT temperature and ambient temperature versus time at each discharge test and the following standard charge;

— discharged capacity in A·h, energy in W·h and average power in W at each discharge test;

— charged capacity in A·h, energy in W·h and average power in W following each discharge test;

— energy round trip efficiency at each discharge test;

— discharged energy in W·h as a function of SOC at each discharge test (in % of rated capacity);

— the EODV of all available cell voltage measuring points for all performed discharge tests;

— determined C/3 rated capacity which is taken as basic value for all further discharge current requirements.

NOTE Capacity data are also used for the later calculation of capacity fades (see 7.7.2.6)

7.2 Energy and capacity at different temperatures and discharge rates

7.2.1 Purpose

This test characterizes the capacity at different temperatures at three different constant current discharge rates. The different discharge rates shall be performed in a sequence before the ambient temperature is changed and the test shall be repeated after the new temperature is achieved.

7.2.2 Test procedure

The test shall be performed at least at four different temperatures (40 °C, 0 °C, –10 °C and –18 °C, the test at T_{min} shall be optional) with the discharge rates C/3, 1C, 2C and the maximum C rate as permitted by the supplier (the maximum C rate corresponds to $I_{d,max}$).

The test sequence shall be performed as specified in Table 2.

Table 2 — Test sequence energy and capacity test at different temperature and discharge rates

Step	Procedure	Ambient temperature
1.1	Thermal equilibration	RT
1.2	Standard charge (SCH)	RT
1.3	Standard cycle (SC)	RT
2.1	Thermal equilibration	40 °C
2.2	Standard charge (SCH) for top off	40 °C
2.3	Discharge at C/3	40 °C
3.1	Thermal equilibration	RT
3.2	Standard charge (SCH)	RT
3.3	Standard cycle (SC)	RT
4.1	Thermal equilibration	40 °C
4.2	Standard charge (SCH) for top off	40 °C
4.3	Discharge at 1C	40 °C
5.1	Thermal equilibration	RT
5.2	Standard charge (SCH)	RT
5.3	Standard cycle (SC)	RT
6.1	Thermal equilibration	40 °C
6.2	Standard charge (SCH) for top off	40 °C
6.3	Discharge at 2C	40 °C
7.1	Thermal equilibration	RT
7.2	Standard charge (SCH)	RT
7.3	Standard cycle (SC)	RT
8.1	Thermal equilibration	40 °C
8.2	Standard charge (SCH) for top off	40 °C
8.3	Discharge at $I_{d,max}$	40 °C
9.1	Thermal equilibration	RT
9.2	Standard charge (SCH)	RT

Table 2 *(continued)*

Step	Procedure	Ambient temperature
9.3	Standard cycle (SC)	RT
10.1	Thermal equilibration	0 °C
10.2	Standard charge (SCH) for top off	0 °C
10.3	Discharge at C/3	0 °C
11.1	Thermal equilibration	RT
11.2	Standard charge (SCH)	RT
11.3	Standard cycle (SC)	RT
12.1	Thermal equilibration	0 °C
12.2	Standard charge (SCH) for top off	0 °C
12.2	Discharge at 1C	0 °C
13.1	Thermal equilibration	RT
13.2	Standard charge (SCH)	RT
13.3	Standard cycle (SC)	RT
14.1	Thermal equilibration	0 °C
14.2	Standard charge (SCH) for top off	0 °C
14.3	Discharge at 2C	0 °C
15.1	Thermal equilibration	RT
15.2	Standard charge (SCH)	RT
15.3	Standard cycle (SC)	RT
16.1	Thermal equilibration	0 °C
16.2	Standard charge (SCH) for top off	0 °C
16.3	Discharge at $I_{d,max}$	0 °C
17.1	Thermal equilibration	RT
17.2	Standard Charge (SCH)	RT
17.3	Standard cycle (SC)	RT
18.1	Thermal equilibration	–10 °C
18.2	Standard charge (SCH) for top off	–10 °C
18.3	Discharge at C/3	–10 °C
19.1	Thermal equilibration	RT
19.2	Standard charge (SCH)	RT
19.3	Standard cycle (SC)	RT
20.1	Thermal equilibration	–10 °C
20.2	Standard charge (SCH) for top off	–10 °C
20.3	Discharge at 1C	–10 °C
21.1	Thermal equilibration	RT
21.2	Standard charge (SCH)	RT
21.3	Standard cycle (SC)	RT
22.1	Thermal equilibration	–10 °C
22.2	Standard charge (SCH) for top off	–10 °C
22.3	Discharge at 2C	–10 °C
23.1	Thermal equilibration	RT
23.2	Standard charge (SCH)	RT
23.3	Standard cycle (SC)	RT

Table 2 *(continued)*

Step	Procedure	Ambient temperature
24.1	Thermal equilibration	–10 °C
24.2	Standard charge (SCH) for top off	–10 °C
24.3	Discharge at $I_{d,max}$	–10 °C
25.1	Thermal equilibration	RT
25.2	Standard Charge (SCH)	RT
25.3	Standard cycle (SC)	RT
26.1	Thermal equilibration	–18 °C
26.2	Standard charge (SCH) for top off	–18 °C
26.3	Discharge at C/3	–18 °C
27.1	Thermal equilibration	RT
27.2	Standard charge (SCH)	RT
27.3	Standard cycle (SC)	RT
28.1	Thermal equilibration	–18 °C
28.2	Standard charge (SCH) for top off	–18 °C
28.3	Discharge at 1C	–18 °C
29.1	Thermal equilibration	RT
29.2	Standard charge (SCH)	RT
29.3	Standard cycle (SC)	RT
30.1	Thermal equilibration	–18 °C
30.2	Standard charge (SCH) for top off	–18 °C
30.3	Discharge at 2C	–18 °C
31.1	Thermal equilibration	RT
31.2	Standard charge (SCH)	RT
31.3	Standard cycle (SC)	RT
32.1	Thermal equilibration	–18 °C
32.2	Standard charge (SCH) for top off	–18 °C
32.3	Discharge at $I_{d,max}$	–18 °C
33.1	Thermal equilibration	RT
33.2	Standard charge (SCH)	RT
33.3	Standard cycle (SC)	RT
34.1	Thermal equilibration	T_{min}
34.2	Standard charge (SCH) for top off	T_{min}
34.3	Discharge at C/3	T_{min}
35.1	Thermal equilibration	RT
35.2	Standard charge (SCH)	RT
35.3	Standard cycle (SC)	RT
36.1	Thermal equilibration	T_{min}
36.2	Standard charge (SCH) for top off	T_{min}
36.3	Discharge at 1C	T_{min}
37.1	Thermal equilibration	RT
37.2	Standard charge (SCH)	RT
37.3	Standard cycle (SC)	RT
38.1	Thermal equilibration	T_{min}

Table 2 *(continued)*

Step	Procedure	Ambient temperature
38.2	Standard charge (SCH) for top off	T_{min}
38.3	Discharge at 2C	T_{min}
39.1	Thermal equilibration	RT
39.2	Standard charge (SCH)	RT
39.3	Standard cycle (SC)	RT
40.1	Thermal equilibration	T_{min}
40.2	Standard charge (SCH) for top off	T_{min}
40.3	Discharge at $I_{d,max}$	T_{min}
41.1	Thermal equilibration	RT
41.2	Standard charge (SCH)	RT
41.3	Standard cycle (SC)	RT

The standard charge (SCH) procedure at the different temperatures shall follow 6.2.2.3.

The standard cycle (SC) procedure shall follow 6.2.

The value for the C discharge rate shall be based on the rated capacity provided by the battery supplier and according to the C/3 test results as described in test procedure 7.1 Energy and capacity test at RT, respectively.

All discharge tests shall be terminated at the supplier's discharge voltage limits.

After discharge, the DUT shall rest at least for 30 min or shall be thermal equilibrated at the requested ambient temperature or a fixed time period shall be used to allow for thermal equilibration before starting the next step in the test sequence.

The test procedure with the ambient temperature T_{min} (–20 °C ≥ T_{min} ≥ –40 °C) within step 34.1 to 41.3 shall be optional.

NOTE Standard charge (SCH) for top off enables the DUT to be recharged in order to compensate for energy losses that can occur during temperature equilibration.

7.2.3 Requirements

The following data shall be reported:

— current, voltage, DUT temperature and ambient temperature versus time at each discharge test and the following standard charge;

— discharged capacity in A·h, energy in W·h and average power in W at each discharge test;

— charged capacity in A·h, energy in W·h and average power in W following each discharge test;

— energy round trip efficiency at each discharge test;

— discharged energy in W·h as a function of SOC at each discharge test (in % of rated capacity);

— a diagram regarding the EODV dispersion of the cells at each discharge test.

7.3 Power and internal resistance

7.3.1 Purpose

The power and internal resistance test is intended to determine the dynamic power capability, the ohmic resistance for discharge and charge conditions as well as the OCV of the DUT as a function of SOC and temperatures according to a realistic load profile derived from vehicle driving operation.

This test applies to battery packs and systems.

7.3.2 Pulse power characterization profile

The objective of this profile is to demonstrate the discharge pulse power (0,1 s, 2 s, 5 s, 10 s, 18 s, 18,1 s, 20 s, 30 s, 60 s, 90 s and 120 s) and regenerative charge pulse power (0,1 s, 2 s, 10 s and 20 s) capabilities at various SOC and temperatures. The test protocol uses constant current at levels derived from the supplier's maximum rated pulse discharge current $I_{dp,max}$. In agreement with the customer, this value can be reduced. Only in case the DUT reaches the discharge voltage limit during discharge, the current shall be reduced such that the battery terminal voltage is maintained at the discharge voltage limit throughout the 120 s discharge pulse. The current of the regenerative charge pulse shall be kept constant and shall be calculated as 75 % of the discharge pulse current. Only in case the DUT reaches the charge voltage limit during charging, the current shall be reduced such that the battery terminal voltage is maintained at the charge voltage limit throughout the 20 s regenerative charge pulse.

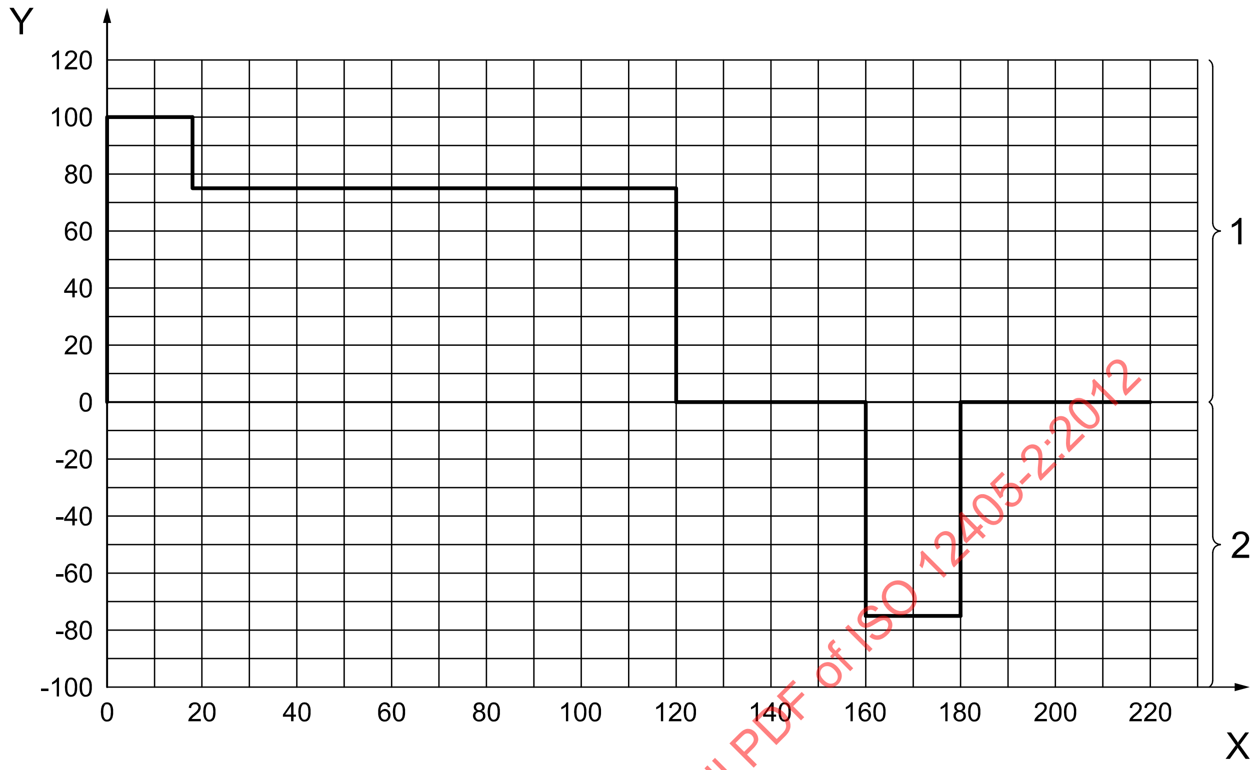
The test profile shall start with an $I_{dp,max}$ discharge pulse for 18 s followed by a $0,75 I_{dp,max}$ discharge pulse for additional 102 s followed by a 40 s rest period to allow the measurement of the cell polarization resistance. After the rest period, a 20 s charge pulse with 75 % current rate of the $I_{dp,max}$ discharge pulse shall be performed to determine the regenerative charge capabilities. After the charge pulse, a rest period of 40 s shall follow (for timing and current see also Table 3 and Figure 5).

NOTE For testing of battery systems the BCU delivers, e.g. depending on actual temperature and SOC of the DUT, the maximum allowed operating limits of the DUT via bus communication to enable the test bench equipment to maintain the DUT always in the specified operating conditions. For testing of battery packs, the supplier is requested to deliver all necessary operating limits for the DUT in order to adjust the test bench equipment to maintain the DUT always in the specified operating conditions.

Table 3 — Pulse power characterization profile

Time increment [s]	Cumulative time [s]	Current
0	0	0
18	18	$I_{dp,max}$
102	120	$0,75\ I_{dp,max}$
40	160	0
20	180	$-0,75\ I_{dp,max}$
40	220	0

Figure 5 shows an example with a maximum rated pulse discharge current $I_{dp,max}$. The discharge current is specified as positive and the charge current as negative. The maximum rated pulse discharge current $I_{dp,max}$ for the pulse power characterization profile has to be specified by the supplier.



Key

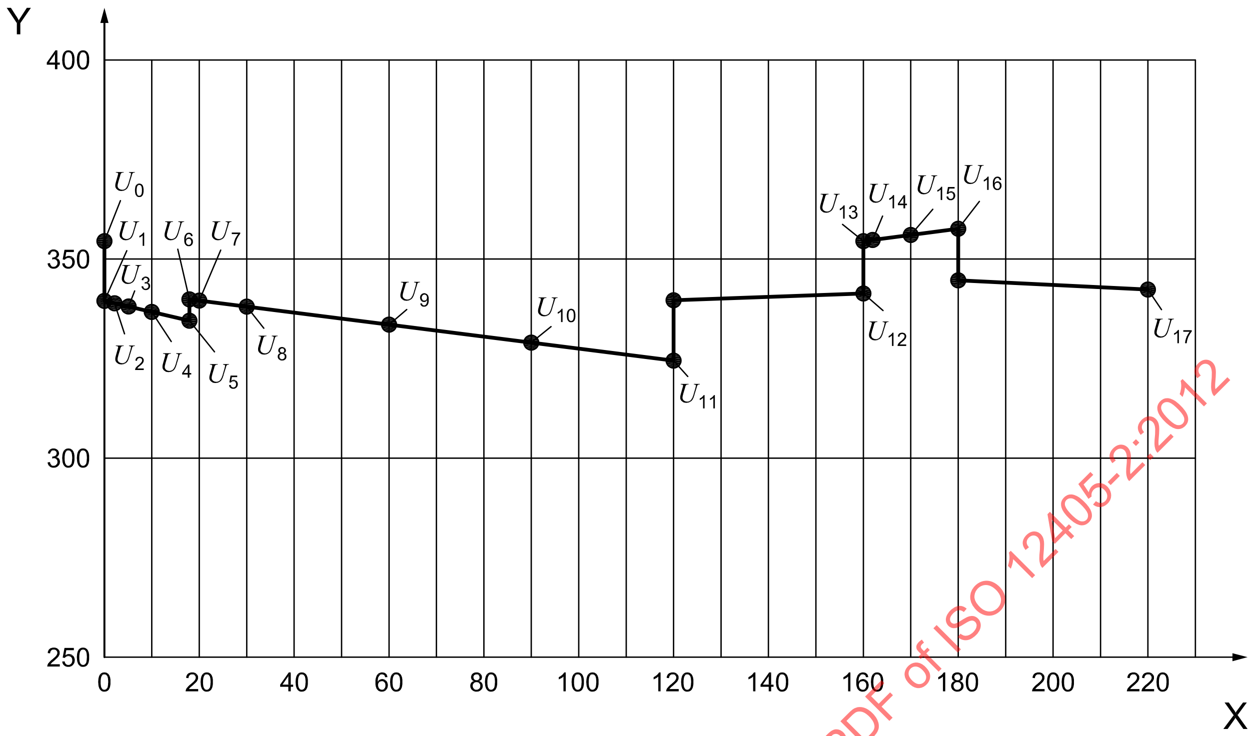
X time [s]

Y current $I_{dp,max}$ [%]

1 discharge

2 charge

Figure 5 — Pulse power characterization profile – current



Key

X time [s]

Y voltage of pack or system (example) [V]

Figure 6 — Pulse power characterization profile – voltage

NOTE The voltage values in Figure 6 are an example and expressed for pack or system level. Values may differ depending on battery chemistry, temperature, SOC, etc.

For the peak power, regenerative power and resistance determination, the battery terminal voltage and current shall be measured at the times given in Table 4.

If the test equipment cannot provide the current value with the requested accuracy at the time of 100 ms after a change in the current profile, no related values for power and resistance shall be calculated for this specific test step.

Table 4 — Measured voltages and currents

Time [s]	Current value	Voltage	Current
0	0	U_0	I_0
0,1	$I_{dp,max}$	U_1	I_1
2	$I_{dp,max}$	U_2	I_2
5	$I_{dp,max}$	U_3	I_3
10	$I_{dp,max}$	U_4	I_4
18	$I_{dp,max}$	U_5	I_5
18,1	0,75 $I_{dp,max}$	U_6	I_6
20	0,75 $I_{dp,max}$	U_7	I_7
30	0,75 $I_{dp,max}$	U_8	I_8
60	0,75 $I_{dp,max}$	U_9	I_9
90	0,75 $I_{dp,max}$	U_{10}	I_{10}
120	0,75 $I_{dp,max}$	U_{11}	I_{11}

Table 4 *(continued)*

Time [s]	Current value	Voltage	Current
160	0	U_{12}	I_{12}
160,1	−0,75 $I_{dp,max}$	U_{13}	I_{13}
162	−0,75 $I_{dp,max}$	U_{14}	I_{14}
170	−0,75 $I_{dp,max}$	U_{15}	I_{15}
180	−0,75 $I_{dp,max}$	U_{16}	I_{16}
220	0	U_{17}	I_{17}

The following calculations for resistance and power shall be performed according to Table 5.

Table 5 — Calculation of resistance and power

Value	Formula	Δt [s]
0,1 s discharge resistance	$R_{i\ 0,1s,dch} = (U_0 - U_1) / I_1$	0,1
2 s discharge resistance	$R_{i\ 2s,\ dch} = (U_0 - U_2) / I_2$	2
5 s discharge resistance	$R_{i\ 5s,dch} = (U_0 - U_3) / I_3$	5
10 s discharge resistance	$R_{i\ 10s,dch} = (U_0 - U_4) / I_4$	10
18 s discharge resistance	$R_{i\ 18s,dch} = (U_0 - U_5) / I_5$	18
18,1 s discharge resistance	$R_{i\ 18,1s,dch} = (U_0 - U_6) / I_6$	18,1
20 s discharge resistance	$R_{i\ 20s,dch} = (U_0 - U_7) / I_7$	20
30 s discharge resistance	$R_{i\ 30s,dch} = (U_0 - U_8) / I_8$	30
60 s discharge resistance	$R_{i\ 60s,dch} = (U_0 - U_9) / I_9$	60
90 s discharge resistance	$R_{i\ 90s,dch} = (U_0 - U_{10}) / I_{10}$	90
120 s discharge resistance	$R_{i\ 120s,dch} = (U_0 - U_{11}) / I_{11}$	120
overall discharge resistance	$R_{i\ dch} = (U_{12} - U_{11}) / I_{11}$	40
0,1 s charge resistance	$R_{i\ 0,1s,cha} = (U_{12} - U_{13}) / I_{13}$	0,1
2 s charge resistance	$R_{i\ 2s,cha} = (U_{12} - U_{14}) / I_{14}$	2
10 s charge resistance	$R_{i\ 10s,cha} = (U_{12} - U_{15}) / I_{15}$	10
20 s charge resistance	$R_{i\ 20s,cha} = (U_{12} - U_{16}) / I_{16}$	20
overall charge resistance	$R_{i\ cha} = (U_{16} - U_{17}) / I_{17}$	20
0,1 s discharge power	$P_{0,1s,dch} = U_1 \times I_1$	0,1
2 s discharge power	$P_{2s,dch} = U_2 \times I_2$	2
5 s discharge power	$P_{5s,dch} = U_3 \times I_3$	5
10 s discharge power	$P_{10s,dch} = U_4 \times I_4$	10
18 s discharge power	$P_{18s,dch} = U_5 \times I_5$	18
18,1 s discharge power	$P_{18,1s,dch} = U_6 \times I_6$	18,1
20 s discharge power	$P_{20s,dch} = U_7 \times I_7$	20
30 s discharge power	$P_{30s,dch} = U_8 \times I_8$	30
60 s discharge power	$P_{60s,dch} = U_9 \times I_9$	60
90 s discharge power	$P_{70s,dch} = U_{10} \times I_{10}$	90
120 s discharge power	$P_{120s,dch} = U_{11} \times I_{11}$	120
0,1 s charge power	$P_{0,1s,cha} = U_{13} \times I_{13}$	0,1
2 s charge power	$P_{2s,cha} = U_{14} \times I_{14}$	2
10 s charge power	$P_{10s,cha} = U_{15} \times I_{15}$	10

Table 5 *(continued)*

Value	Formula	Δt [s]
20 s charge power	$P_{20s,cha} = U_{16} \times I_{16}$	20
open circuit voltage	$U_{OCV} = U_{17}$	

7.3.3 Test procedure

The test shall be performed at six different temperatures (40 °C, RT, 0 °C, –10 °C, –18 °C and –25 °C) and shall cover a SOC range of 90 % to 20 % within five steps (90 %, 70 %, 50 %, 35 %, 20 %) whereas the last step at 20 % SOC shall only be performed if the maximum discharge current of the DUT is equal to or less than a 5C current rate in order to avoid a deep discharge of the DUT.

— Prior to each test temperature, the DUT shall be conditioned at RT according to the thermal equilibration requirements provided in 5.1 followed by a standard charge (SCH) as provided in 6.2.2.3 for top off and a standard cycle (SC) as provided in 6.2.

— Then the DUT shall be conditioned at the specified test temperature according to the thermal equilibration requirements provided in 5.1 followed by a standard charge (SCH) as provided in 6.2.2.3. The standard charge (SCH) is requested in order to condition the DUT to 100 % SOC at the specified test temperature prior to the pulse power characterization test profile.

— In the next step, the fully charged DUT shall be discharged with a C/3 rate to the initial SOC of 90 % followed by a minimum 30 min rest period.

NOTE A 108 s discharge with a C/3 rate will decrease the SOC level by 1 %.

— Then the pulse power characterization profile as described in 7.3.2 shall be performed.

— The next SOC steps (70 %, 50 %, 35 %, and 20 %[1]) shall be reached by a C/3 discharge followed by a 30 min rest period. Then the pulse power characterization profile as described in 7.3.2 shall be performed at each mentioned SOC step.

NOTE The amount of electric charge [A·h] withdrawn during the previous power characterization profile needs to be taken into account when adjusting the SOC level to the next following step by a C/3 discharge.

— At the end of the pulse power characterization profile at the 20 % SOC level, the standard charge (SCH) shall be performed.

— Data sampling, especially for DUT voltage and current, shall be performed with an adequate sampling rate for the profile described in Figure 6 and Table 4. A minimum of 10 measuring points per step are required.

— The complete test sequence shall be performed as specified in Table 6.

Table 6 — Test sequence power and internal resistance test

Step	Procedure	Ambient temperature
1.1	Thermal equilibration	RT
1.2	Standard charge (SCH) for top off	RT
1.3	Standard cycle (SC)	RT
2.1	Thermal equilibration	RT
2.2	Standard charge (SCH) for top off	RT
2.3	Pulse power characterization	RT
2.4	Standard charge (SCH)	RT

1) If possible.

Table 6 *(continued)*

Step	Procedure	Ambient temperature
3.1	Thermal equilibration	RT
3.2	Standard charge (SCH) for top off	RT
3.3	Standard cycle (SC)	RT
4.1	Thermal equilibration	40 °C
4.2	Standard charge (SCH) for top off	40 °C
4.3	Pulse power characterization	40 °C
4.4	Standard charge (SCH)	40 °C
5.1	Thermal equilibration	RT
5.2	Standard charge (SCH) for top off	RT
5.3	Standard cycle (SC)	RT
6.1	Thermal equilibration	0 °C
6.2	Standard charge (SCH) for top off	0 °C
6.3	Pulse power characterization	0 °C
6.4	Standard charge (SCH)	0 °C
7.1	Thermal equilibration	RT
7.2	Standard charge (SCH) for top off	RT
7.3	Standard cycle (SC)	RT
8.1	Thermal equilibration	–10 °C
8.2	Standard charge (SCH) for top off	–10 °C
8.3	Pulse power characterization	–10 °C
8.4	Standard charge (SCH)	–10 °C
9.1	Thermal equilibration	RT
9.2	Standard charge (SCH) for top off	RT
9.3	Standard cycle (SC)	RT
10.1	Thermal equilibration	–18 °C
10.2	Standard charge (SCH) for top off	–18 °C
10.3	Pulse power characterization	–18 °C
10.4	Standard charge (SCH)	–18 °C
11.1	Thermal equilibration	RT
11.2	Standard charge (SCH) for top off	RT
11.3	Standard cycle (SC)	RT
12.1	Thermal equilibration	–25 °C
12.2	Standard charge (SCH) for top off	–25 °C
12.3	Pulse power characterization	–25 °C
12.4	Standard charge (SCH)	–25 °C
13.1	Thermal equilibration	RT
13.2	Standard charge (SCH) for top off	RT
13.3	Standard cycle (SC)	RT
14.1	Thermal equilibration	RT
14.2	Standard charge (SCH) for top off	RT
14.3	Pulse power characterization	RT
14.4	Standard charge (SCH)	RT

— The standard charge (SCH) procedure at the different temperatures shall follow 6.2.2.3.

— The standard cycle (SC) procedure shall follow 6.2.

— All discharge tests shall be terminated at the supplier's discharge voltage limits.

NOTE Standard charge (SCH) for top off enables the DUT to be recharged in order to compensate for energy losses that can occur during temperature equilibration.

7.3.4 Requirements

The following data shall be delivered by using the equations described in 7.3.2:

— discharge power for 0,1 s, 2 s, 5 s, 10 s, 18 s, 18,1 s, 20 s, 30 s, 60 s, 90 s and 120 s peaks as a function of SOC and temperature;

— regenerative power for 0,1 s, 2 s, 10 s and 20 s peaks as a function of SOC and temperature;

— discharge resistance for 0,1 s, 2 s, 5 s, 10 s, 18 s, 18,1 s, 20 s, 30 s, 60 s, 90 s and 120 s peaks as well as the overall resistance as a function of SOC and temperature;

— charge resistance for 0,1 s, 2 s, 10 s and 20 s peaks as well as the overall resistance as a function of SOC and temperature;

— open circuit voltage as a function of SOC and temperature;

— deviation from first and last test at RT, if any;

— temperature versus time of the DUT at the specified tests;

— if the charge or discharge current had to be reduced due to voltage limits, the calculated internal resistance values shall be marked clearly in the protocol and in the result tables.

7.4 Energy efficiency at fast charging

7.4.1 Purpose

The purpose of the energy efficiency at fast charging test is to determine the battery system behaviour and the energy efficiency at different fast charging levels. For high-energy application, the energy efficiency also at fast charging of the used battery system has a significant influence on the overall vehicle efficiency.

This test applies to battery systems only.

7.4.2 Test procedure

The test shall be performed with battery systems at RT, 0 °C and T_{min} and three different fast charging levels (1C, 2C and $I_{c,max}$). After thermal equilibration and conditioning of the DUT by a standard cycle, the DUT first shall be discharged via a standard discharge followed in the next step by a fast charge with a starting current of 1C, 2C and $I_{c,max}$. The charge regime, the maximum charge current $I_{c,max}$ and the minimum ambient test temperature T_{min} shall follow the requirements delivered by the supplier.

The test sequence shall be performed as specified in Table 7.

Table 7 — Test sequence energy efficiency at fast charging test

Step	Procedure	Ambient temperature
1.1	Thermal equilibration	RT
1.2	Standard charge (SCH)	RT
1.3	Standard cycle (SC)	RT
2.1	Standard discharge (SDCH)	RT

Table 7 *(continued)*

Step	Procedure	Ambient temperature
2.2	Fast charge with 1C	RT
2.3	Rest period for 60 min at open voltage class B circuit	RT
2.4	Standard cycle (SC)	RT
2.5	Standard discharge (SDCH)	RT
2.6	Fast charge with 2C	RT
2.7	Rest period for 60 min at open voltage class B circuit	RT
2.8	Standard cycle (SC)	RT
2.9	Standard discharge (SDCH)	RT
2.10	Fast charge with $I_{c,max}$	RT
2.11	Rest period for 60 min at open voltage class B circuit	RT
3.1	Standard cycle (SC)	RT
3.2	Thermal equilibration	0 °C
4.1	Standard discharge (SDCH)	0 °C
4.2	Fast charge with 1C	0 °C
5.1	Thermal equilibration	RT
5.2	Standard charge (SC) for top off	RT
5.3	Standard cycle (SC)	RT
5.4	Thermal equilibration	0 °C
6.1	Standard discharge (SDCH)	0 °C
6.2	Fast charge with 2C	0 °C
7.1	Thermal equilibration	RT
7.2	Standard charge (SC) for top off	RT
7.3	Standard cycle (SC)	RT
7.4	Thermal equilibration	0 °C
8.1	Standard discharge (SDCH)	0 °C
8.2	Fast charge with $I_{c,max}$	0 °C
9.1	Thermal equilibration	RT
9.2	Standard charge (SC) for top off	RT
9.3	Standard cycle (SC)	RT
9.4	Thermal equilibration	T_{min}
10.1	Standard discharge (SDCH)	T_{min}
10.2	Fast charge with $I_{c,max}$	T_{min}
11.1	Thermal equilibration	RT
11.2	Standard charge (SC) for top off	RT
11.3	Standard cycle (SC)	RT

The standard charge (SCH) procedure at the different temperatures shall follow 6.2.2.3.

The standard cycle (SC) procedure shall follow 6.2.

All discharge tests shall be terminated at the supplier's discharge voltage limits.

All fast charge tests shall follow or shall be terminated at the supplier's requested limits.

The sampling rate for test data during testing shall be ≤ 50 ms.

Calculate energy efficiency for the following ΔSOCs:

— from SOC at discharge test termination to the next rounded SOC decade and each following 10 % SOC increment up to the SOC level at fast charge termination,

— from each rounded SOC decade following the discharge test termination to each following 10 % SOC increment up to the SOC level at fast charge termination,

based on measured voltage and current data for each standard discharge and the following fast charge test. Use the following formula for calculation of the requested energy efficiency values:

$$\eta = \left| \frac{\int_{t_{start}}^{t_{end}} U \cdot I_{discharge} \cdot dt}{\int_{t_{start}}^{t_{end}} U \cdot I_{charge} \cdot dt} \right| \times 100 \; [\%]$$

7.4.3 Requirement

The following data shall be reported:

— current, voltage, DUT temperature and ambient temperature versus time at each discharge test and the following fast charge;

— discharged capacity in A·h, energy in W·h and average power in W at each discharge test;

— charged capacity in A·h, energy in W·h and average power in W following each discharge test;

— the EODV of all available cell voltage measuring points for all performed discharge tests;

— energy efficiency for specified ΔSOCs at each standard discharge – fast charge test.

7.5 No load SOC loss

7.5.1 Purpose

The purpose of this test is to measure the SOC loss of a battery system if it is not used for an extended period of time. This test refers to a scenario that a vehicle is in parking mode without charging for a longer time period and therefore the battery system could not be placed on charge. The no load SOC loss, if it occurs, may be due to self-discharge, which is normally temporary, or to other mechanisms that could produce permanent or semi-permanent loss of SOC.

This test applies to battery systems only.

7.5.2 Test procedure

The no load SOC loss shall be measured with a complete and fully operational battery system. The BCU shall be supplied with the necessary auxiliary power (e.g. 12 V d.c. power supply) in order to be able to control necessary battery system functions during the rest period, for example:

— battery system cell balancing;

— periodical BCU wake-up activities.

The no load SOC loss rate[s] shall include any possible parasitic or operational discharge contribution of the cell balancing circuitry itself beyond the inherent self-discharge rate of the battery cells themselves.

The no load SOC loss rate of the battery system shall be measured for three different rest periods and at two different temperatures. The battery system shall be conditioned to 100 % SOC by a standard cycle (SC) and then left at open circuit for a certain time. The BCU shall be able to perform control activities (e.g. cell balancing, regular wake-up activities). After the rest period, the remaining SOC shall be determined by a C/3 discharge at RT.

The tests shall be performed in a temperature controlled test chamber at the given temperatures. Before each test cycle at a given temperature, the battery shall be kept at the test temperature for a minimum of 12 h. This period can be reduced if thermal equilibration is reached, specified as less than 4 K change among individual cell temperatures during an interval of 1 h.

Temperatures: RT and 40 °C.

Standard cycle: To ensure that each test is done with the battery system in the same initial condition, an SC (see 6.2) shall be performed prior to each test.

Discharge rate: No discharge after the SC requested, the battery system shall be at 100 % SOC. If supplier and customer agreed to a lower SOC, the battery system shall be discharged after the SC at a C/3 rate to adjust the agreed SOC prior to the rest period.

Rest period: 48 h (2 d), 168 h (7 d) and 720 h (30 d).

Auxiliary energy: The auxiliary energy consumption (e.g. 12 V d.c. level) for the BCU and, if required, for other battery system electronics shall be measured continuously and expressed in W·h for each rest period.

NOTE The test can be performed in sequence with a single DUT or in parallel with multiple DUTs.

7.5.3 Test sequence

1st test sequence: Rest period at RT

Table 8 — Test sequence no load SOC loss at RT

Step	Procedure	Ambient temperature
1.1	Thermal equilibration	RT
1.2	Standard charge (SCH)	RT
1.3	Standard cycle (SC)	RT
1.4	Rest period at open voltage class B circuit for 48 h	RT
1.5	Standard cycle (SC)	RT
1.6	Rest period at open voltage class B circuit for 168 h	RT
1.7	Standard cycle (SC)	RT
1.8	Rest period at open voltage class B circuit for 720 h	RT
1.9	Standard cycle (SC)	RT

All discharge tests shall be terminated if the supplier's requested discharge voltage limits are reached.

NOTE The remaining capacity will be measured within steps 1.5, 1.7 and 1.9 during the standard discharge (SDCH) test, which is the first part of the standard cycle (SC) test.

2nd test sequence: Rest period at 40 °C (or higher according to agreement between supplier and customer)

Table 9 — Test sequence no load SOC loss at 40 °C (or higher)

Step	Procedure	Ambient temperature
2.1	Thermal equilibration	RT
2.2	Standard charge (SCH)	RT
2.3	Standard cycle (SC)	RT

Table 9 *(continued)*

Step	Procedure	Ambient temperature
2.4	Rest period at open voltage class B circuit for 48 h	40 °C (or higher)
2.5	Thermal equilibration	RT
2.6	Standard cycle (SC)	RT
2.7	Rest period at open voltage class B circuit for 168 h	40 °C (or higher)
2.8	Thermal equilibration	RT
2.9	Standard cycle (SC)	RT
2.10	Rest period at open voltage class B circuit for 720 h	40 °C (or higher)
2.11	Thermal equilibration	RT
2.12	Standard cycle (SC)	RT

All discharge tests shall be terminated if the supplier's requested discharge voltage limits are reached.

NOTE The remaining capacity will be measured within steps 2.6, 2.9 and 2.12 during the standard discharge (SDCH) test, which is the first part of the standard cycle (SC) test.

7.5.4 Requirement

The remaining C/3 energy and SOC from the initial 100 % SOC shall be reported. The loss of energy and SOC after each rest period shall be expressed as a percentage of the initial 100 % SOC.

The auxiliary energy consumption (12 V d.c. level) for the BCU and if required for other battery system electronics shall be expressed in W·h for each rest period.

A graph, including data for the three rest periods and the two test temperatures, showing residual capacity versus rest period shall be presented.

7.6 SOC loss at storage

7.6.1 Purpose

The purpose of this test is to measure the SOC loss at storage of a battery system if it is stored for an extended period of time. This test refers to a scenario when the battery system is shipped from a supplier to a customer. This SOC loss at storage, if it occurs, may be due to self-discharge, which is normally temporary, or to other mechanisms that could produce permanent or semi-permanent loss of SOC.

This test applies to battery systems only.

7.6.2 Test procedure

The SOC loss at storage behaviour shall be measured with a complete and fully operational battery system. During the storage period, all battery system terminals shall be disconnected (e.g. voltage class B connections, voltage class A connection, cooling). The service disconnect device, if any, shall be disconnected.

The SOC loss at storage of the battery system shall be measured after a 720 h (30 d) rest period at 45 °C ambient temperature with an initial SOC of 50 % or higher, if agreed between supplier and customer. The remaining SOC after the storage period shall be determined by a C/3 discharge.

The SOC loss at storage test shall be performed in a temperature controlled test chamber.

Temperature: 45 °C.

Standard cycle: To ensure that each test is done with the battery system in the same initial condition, an SC (see 6.2) shall be performed prior to the SOC loss at storage test.

Discharge rate: Discharge the battery system to 50 % SOC at C/3 rate. A higher SOC value can be agreed between supplier and customer.

Rest period: 720 h (30 d).

Auxiliary energy: During the storage period, all connections at the battery system are disconnected.

Service disconnect: The service disconnect device, if any, shall be disconnected.

7.6.3 Test sequence

Table 10 — Test sequence capacity loss at storage

Step	Procedure	Ambient temperature
1	Thermal equilibration	RT
2	Standard charge (SCH)	RT
3	Standard cycle (SC)	RT
4	Discharge C/3 to 50 % SOC	RT
5	Rest period for 720 h, all voltage class B and voltage class A terminals are disconnected, service disconnect is disconnected	45 °C
6	Thermal equilibration	RT
7	Standard cycle (SC)	RT

All discharge tests shall be terminated if the supplier's requested discharge voltage limits are reached.

NOTE The remaining SOC will be measured within step 7 during the standard discharge (SDCH) test, which is the first part of the standard cycle (SC) test.

7.6.4 Requirement

The remaining C/3 energy and SOC from the initial SOC shall be reported. The loss of energy and SOC after the rest period shall be expressed as a percentage of the initial SOC.

7.7 Cycle life

7.7.1 Purpose

In addition to other ageing factors (i.e. time, temperature), the energy throughput has a significant influence on the lifetime of a battery.

For choosing a relevant ageing profile concerning the energy throughput, the real conditions during driving shall be considered. That means the applied power profiles for battery systems for dynamic discharge applications and in addition the proposed SOC swing for battery systems for charge-depleting followed by charge-sustaining applications shall cover the vehicle demands in a proper way. In order to get reliable and significant data for lifetime prediction, it is important that supplier and customer agree on the basic data of the test profiles.

On the other hand, the battery system shall not be stressed too much. Therefore the thermal management and monitoring of the battery system is mandatory, and certain rest phases are needed for equilibrium and cell balancing.

This test applies to battery systems only.

7.7.2 Test procedure

The procedure delivers two sets of test procedures, dedicated to battery systems used in dynamic discharge applications followed by a complete charging procedure, see 7.7.2.1, and for battery systems used in dynamic discharge applications followed first by a charge sustainable operation within a moderate SOC swing and then followed by a complete charging procedure, see 7.7.2.2. Supplier and customer shall agree on the relevant test procedure based on the dedicated application requirements for the battery system.

7.7.2.1 Battery systems for dynamic discharge applications

7.7.2.1.1 Preparation

During the test, it is necessary to maintain the DUT temperature by its cooling equipment within a temperature range between RT and 40 °C (i.e. RT during rest periods, certainly higher during operation). If requested by the supplier, additional rest periods can be placed between the cycles in order to keep the DUT within the designated temperature range.

The cycle test is performed by combining two test profiles: one is the “dynamic discharge power profile A”, where the amount of discharged energy is significantly lower than the “dynamic discharge power profile B”. The profiles are shown in Figure 7 and Figure 8.

The SOC range shall be defined by the customer, otherwise the cycle test shall be performed between 100 % and 20 % SOC.

The cycle test shall be started from the upper limit of SOC with a sequence by performing the dynamic discharge power profile A, followed by the dynamic discharge power profile B and then followed by the dynamic discharge power profile A until the SOC reaches the lower limit or the battery voltage reaches the lower voltage limit specified by the supplier. Within the next step, the battery system shall be charged according to the supplier’s recommendation to the upper limit of SOC with the requirement to maintain the total time for the discharge–charge cycle including a rest time for cell balancing to 8 h. This sequence of dynamic discharge power profiles including charging shall be repeated during the following 28 d. After these cycling activities the capacity and pulse power characterization tests shall be performed to determine the current status of the battery system. After this performance testing, the life cycling testing shall be continued until the test has been terminated according to the specified criteria; see end of test criteria in 7.7.2.5.

The SOC limit can be detected by one of the following:

— SOC calculated, i.e. by the BCU for a battery system test;

— A·h counted by external measurement;

— battery voltage upper and lower limits defined by the supplier.

7.7.2.1.2 Test sequence battery system cycle life test for dynamic discharge applications

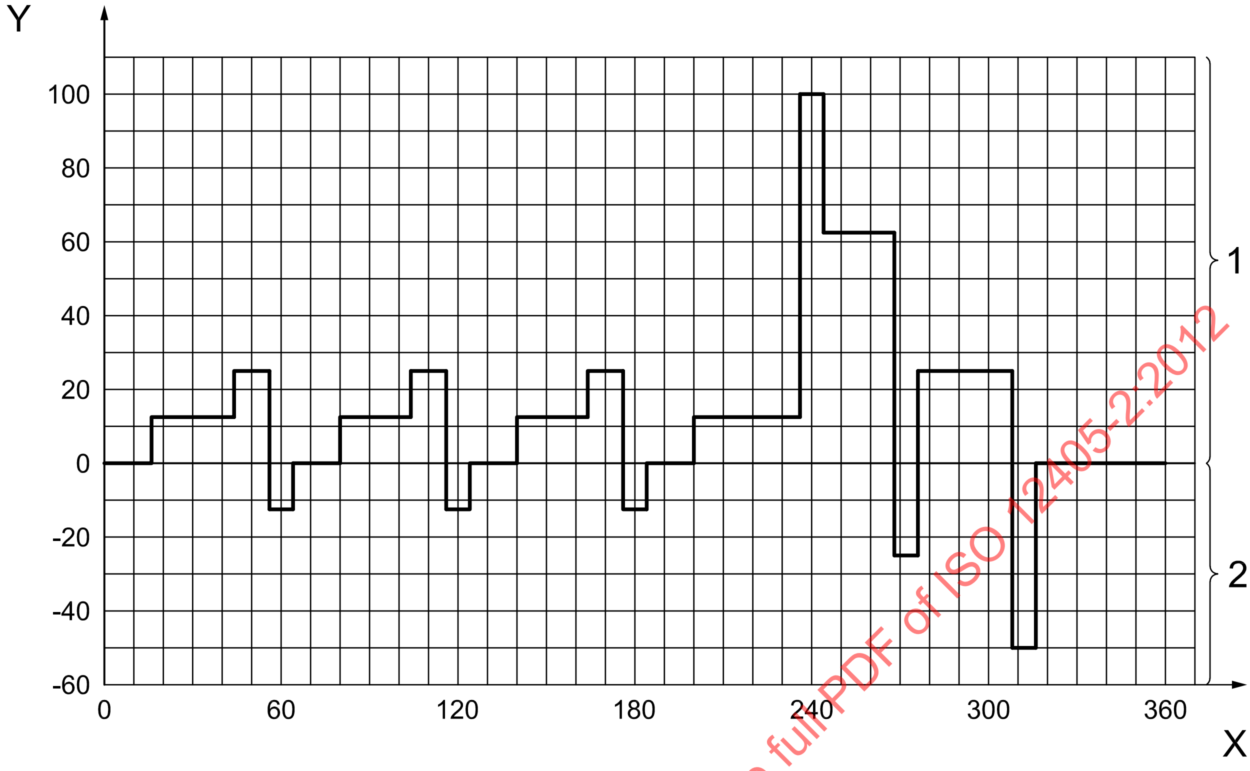
Table 11 — Test sequence battery system cycle life test for dynamic discharge applications

Step	Procedure	Ambient temperature
1	Thermal equilibration	RT
2	Standard cycle (SC)	RT
3	Standard cycle (SC) for C/3 capacity determination	RT
4	Thermal equilibration	–10 °C
5	Standard charge (SCH) for top off	–10 °C
6	Standard cycle (SC) for C/3 capacity determination	–10 °C
7	Thermal equilibration	RT
8	Standard cycle (SC)	RT

Table 11 *(continued)*

Step	Procedure	Ambient temperature
9	Cycling by performing the sequence of dynamic discharge power profile A, followed by the dynamic discharge power profile B and then followed by the dynamic discharge power profile A until: — SOC 20 % or other lower limit SOC defined by customer is reached — Battery voltage reaches lower limit defined by the supplier	RT
10	Charging to 100 % SOC as defined by the supplier with the following requirements: — Charging including cell balancing activities and rest time shall be finished at least 8 h after starting the dynamic discharge profile A	RT
11	Repeat steps 9 to 11 for a total of 28 d	
12	Thermal equilibration	RT
13	Standard cycle (SC)	RT
14	Standard cycle (SC) for C/3 capacity determination	RT
15	Thermal equilibration	RT
16	Standard charge (SCH) for top off	RT
17	Pulse power characterization	RT
18	Standard charge (SCH)	RT
19	Every 8 weeks continue with step 20, otherwise with step 9	
20	Thermal equilibration	–10 °C
21	Standard charge (SCH) for top off	–10 °C
22	Standard cycle (SC) for C/3 capacity determination	–10 °C
23	Thermal equilibration	RT
24	Standard cycle (SC)	RT
25	Thermal equilibration	–10 °C
26	Standard charge (SCH) for top off	–10 °C
27	Pulse power characterization	–10 °C
28	Thermal equilibration	RT
29	Standard cycle (SC)	RT
30	Continue with step 9	RT

7.7.2.1.3 Test profiles for cycle life test



Key

X time [s]

Y fraction of P_{max} [%]

1 discharge

2 charge

Figure 7 — Profile for cycle life test – Dynamic discharge power profile A

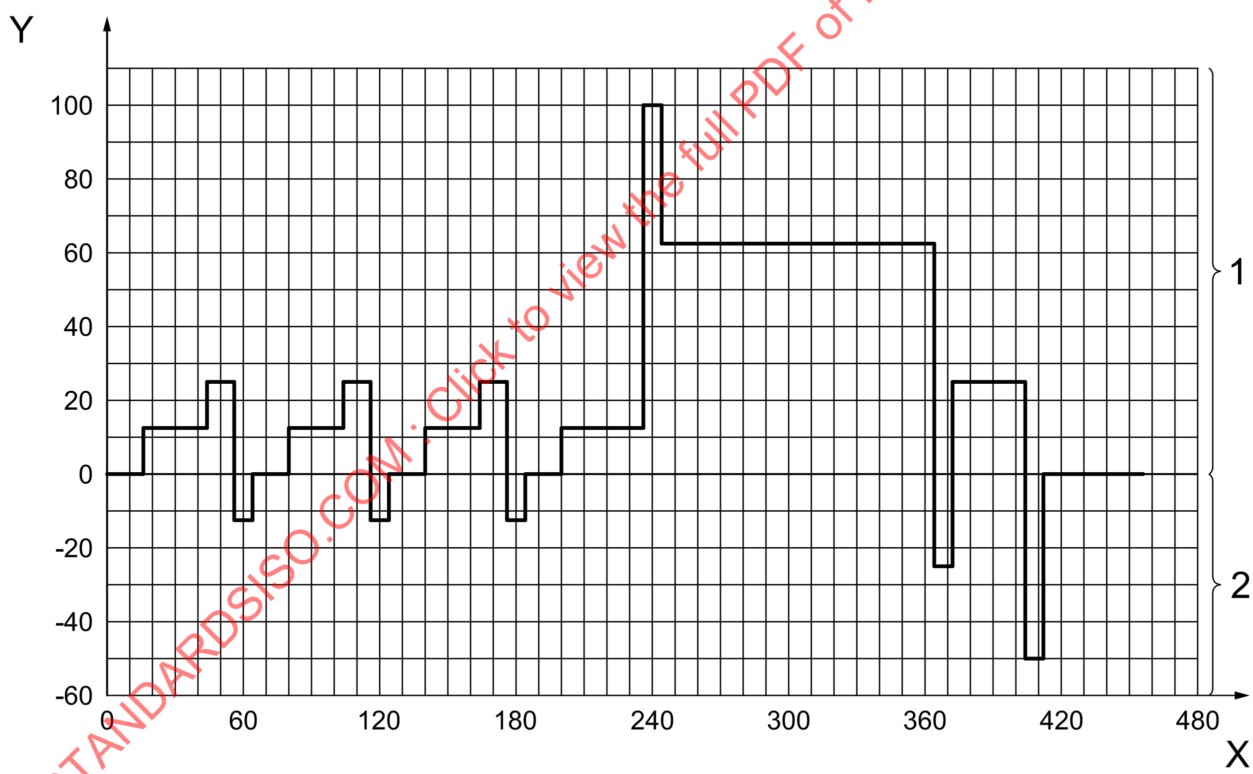
Table 12 — Time and power data – Dynamic discharge power profile A

Step	Time increment [s]	Time cumulative [s]	Fraction of max. power [%]
1	16	16	0
2	28	44	+12,5
3	12	56	+25
4	8	64	–12,5
5	16	80	0
6	24	104	+12,5
7	12	116	+25
8	8	124	–12,5
9	16	140	0
10	24	164	+12,5
11	12	176	+25
12	8	184	–12,5
13	16	200	0
14	36	236	+12,5

Table 12 *(continued)*

Step	Time increment [s]	Time cumulative [s]	Fraction of max. power [%]
15	8	244	+100
16	24	268	+62,5
17	8	276	−25
18	32	308	+25
19	8	316	−50
20	44	360	0

In this profile, the max. power shall be the power value $P_{10s,dch}$, measured in the power and internal resistance test as described in 7.3 at RT, 35 % SOC and $t = 10$ s unless customer and supplier have agreed on a reduction of this power value.



Key

X time [s]

Y fraction of P_{max} [%]

1 discharge

2 charge

Figure 8 — Profile for cycle life test – Dynamic discharge power profile B

Table 13 — Time and power data – Dynamic discharge power profile B

Step	Time increment [s]	Time cumulative [s]	Fraction of max. power [%]
1	16	16	0
2	28	44	+12,5
3	12	56	+25
4	8	64	–12,5
5	16	80	0
6	24	104	+12,5
7	12	116	+25
8	8	124	–12,5
9	16	140	0
10	24	164	+12,5
11	12	176	+25
12	8	184	–12,5
13	16	200	0
14	36	236	+12,5
15	8	244	+100
16	120	364	+62,5
17	8	372	–25
18	32	404	+25
19	8	412	–50
20	44	456	0

In this profile, the max. power shall be the power value $P_{10s,dch}$, measured in the power and internal resistance test as described in 7.3 at RT, 35 % SOC and t = 10 s unless customer and supplier have agreed on a reduction of this power value.

7.7.2.1.4 Conditions

— Ambient: start at RT in a temperature chamber with adequate safety equipment.

— Designated (or comparable) battery cooling system shall operate.

— During cycling, the DUT electronic shall ensure that no cell limits will be exceeded, by achieving voltage limits as specified by the supplier. The current has to be reduced automatically to avoid any abuse operation.

7.7.2.2 Battery systems for charge-depleting followed by charge-sustaining applications

7.7.2.2.1 Preparation

During the test, it is necessary to maintain the DUT temperature by its cooling equipment within a temperature range between RT and 40 °C (i.e. RT during rest periods, certainly higher during operation). If requested by the supplier, additional rest periods can be placed between the cycles in order to keep the DUT within the designated temperature range.

The cycle test is performed by combining the power profile cycling for charge-depleting applications as described in 7.7.2.1 and a charge-sustaining cycle composed of a “plug-in charge-rich profile” where the charge amount is slightly larger than the discharge amount, and a “plug-in discharge-rich profile” where the discharge amount is slightly larger than the charge amount, as shown in Figure 9 and Figure 10.

The cycle test shall be started from the upper limit of SOC by performing the power profile cycling for charge-depleting applications as described in 7.7.2.1 until the SOC reaches the lower limit for the charge-depleting operation of 30 % SOC or as specified by the customer, followed by a sequence of the plug-in charge-rich current profile and the plug-in discharge-rich current profile. The SOC swing range during the charge-sustaining cycling shall be defined by the customer, otherwise the cycle test shall be performed between 35 % and 25 % SOC for the following 2 h. Within the next step, the battery system shall be charged according to the supplier's recommendation to the upper limit of SOC with the requirement to maintain the total time for the discharge–charge cycle including a rest time for cell balancing to 8 h. This sequence of dynamic discharge profiles including charging shall be repeated during the following 28 d. After these cycling activities the capacity and pulse power characterization tests shall be performed to determine the current status of the battery system. After the performance testing, the life cycling testing shall be continued until the test has been terminated according to the specified criteria; see end of test criteria in 7.7.2.5.

The SOC limit for altering the profiles can be detected by one of the following:

— SOC calculated, i.e. by the BCU for a battery system test;

— A·h counted by external measurement;

— battery voltage upper and lower limit defined by the supplier.

7.7.2.2.2 Test sequence battery system cycle life test for charge-depleting followed by charge-sustaining applications

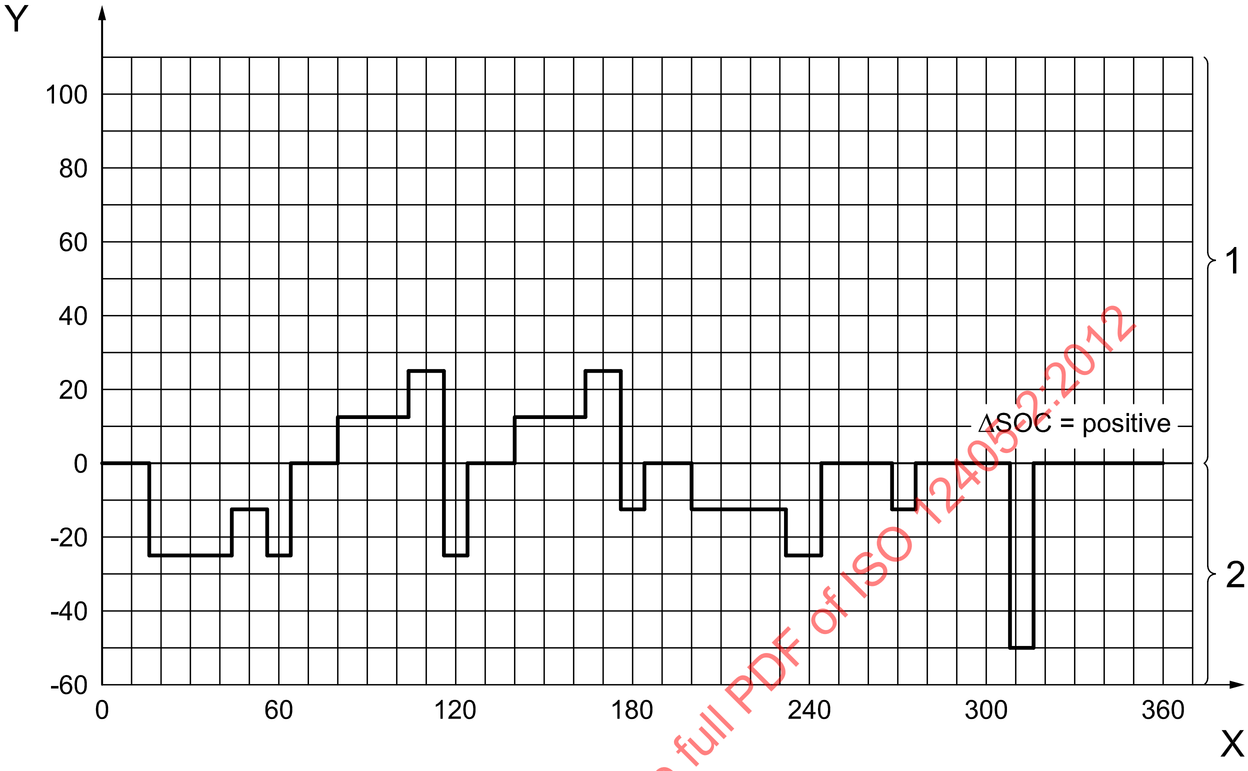
Table 14 — Test sequence battery system cycle life test for charge-depleting followed by charge-sustaining applications

Step	Procedure	Ambient temperature
1	Thermal equilibration	RT
2	Standard cycle (SC)	RT
3	Standard cycle (SC) for C/3 capacity determination	RT
4	Thermal equilibration	–10 °C
5	Standard charge (SCH) for top off	–10 °C
6	Standard cycle (SC) for C/3 capacity determination	–10 °C
7	Thermal equilibration	RT
8	Standard cycle (SC)	RT
9	Cycling by performing the power profile cycling for charge-depleting applications as described in 7.7.2.1 until: — SOC 30 % or other lower limit SOC defined by customer is reached	RT
10	Cycling by the plug-in charge-rich current profile until: — SOC 35 % or other upper limit SOC defined by customer — Battery voltage reaches upper limit defined by the supplier	RT
11	Cycling by the plug-in discharge-rich current profile until: — SOC 25 % or other lower limit SOC defined by the customer — Battery voltage reaches lower limit defined by the supplier	RT
12	Repeat steps 10 to 11 for 2 h	
13	Charge to 100 % SOC as defined by the supplier with the following requirements: — Charging including cell balancing activities and rest time shall be finished at least 8 h after starting the cycling with step 9	RT
14	Repeat steps 9 to 14 for a total of 28 d	
15	Thermal equilibration	RT
16	Standard cycle (SC)	RT

Table 14 *(continued)*

Step	Procedure	Ambient temperature
17	Standard cycle (SC) for C/3 capacity determination	RT
18	Thermal equilibration	RT
19	Standard charge (SCH) for top off	RT
20	Pulse power characterization	RT
21	Standard charge (SCH)	RT
22	Every 8 weeks continue with step 23, otherwise with step 9	
23	Thermal equilibration	–10 °C
24	Standard charge (SCH) for top off	–10 °C
25	Standard cycle (SC) for C/3 capacity determination	–10 °C
26	Thermal equilibration	RT
27	Standard cycle (SC)	RT
28	Thermal equilibration	–10 °C
29	Standard charge (SCH) for top off	–10 °C
30	Pulse power characterization	–10 °C
31	Thermal equilibration	RT
32	Standard cycle (SC)	RT
33	Continue with step 9	RT

7.7.2.2.3 Test profiles for cycle life test



Key

X time [s]

Y current $I_{dp,max}$ [%]

1 discharge

2 charge

Figure 9 — Profile for cycle life test – Plug-in charge-rich current profile

Table 15 — Time and current data – Plug-in charge-rich current profile

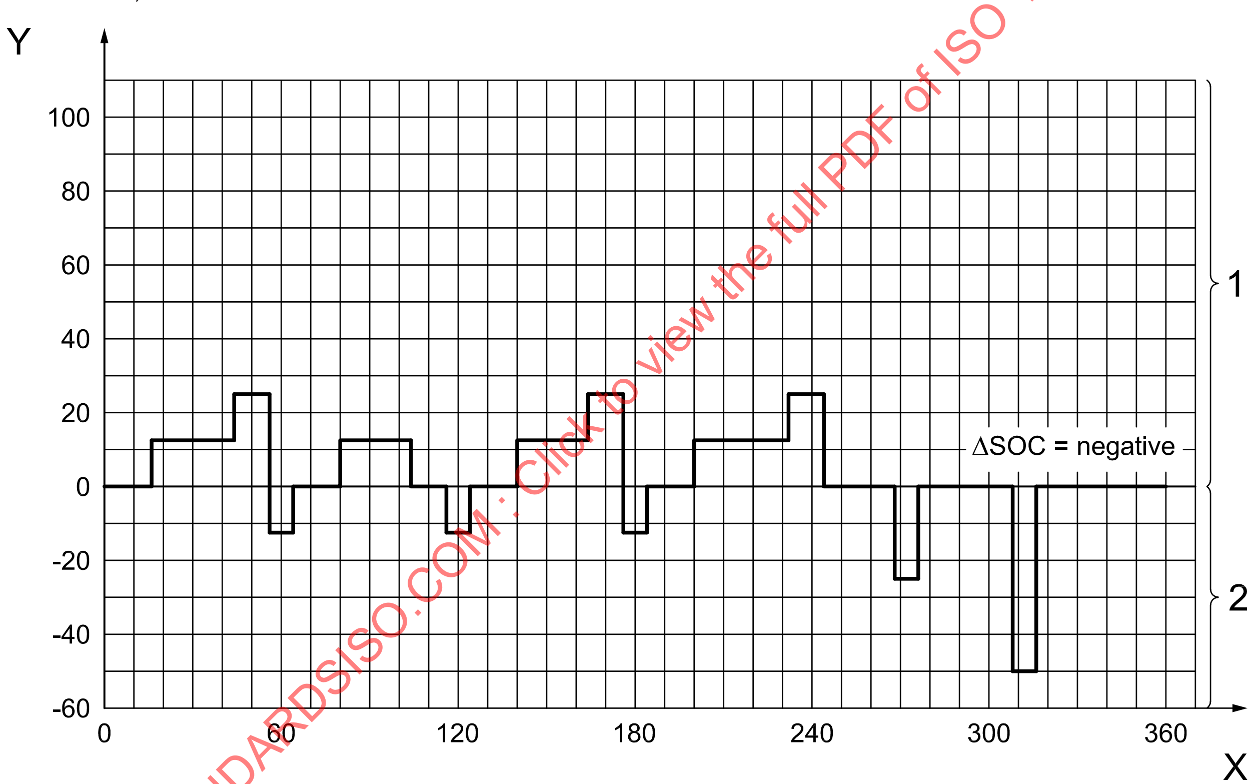
Step	Time increment [s]	Time cumulative [s]	Fraction of I_{max} [%]
1	16	16	0
2	28	44	–25
3	12	56	–12,5
4	8	64	–25
5	16	80	0
6	24	104	+12,5
7	12	116	+25
8	8	124	–25
9	16	140	0
10	24	164	+12,5
11	12	176	+25
12	8	184	–12,5
13	16	200	0
14	32	232	–12,5

Table 15 *(continued)*

Step	Time increment [s]	Time cumulative [s]	Fraction of I_{max} [%]
15	12	244	–25
16	24	268	0
17	8	276	–12,5
18	32	308	0
19	8	316	–50
20	44	360	0

NOTE Because of different time delays and slew rates of various battery testers which will be used, no shorter pulses than 5 s are defined.

In this profile, I_{max} shall be the maximum rated pulse discharge current $I_{dp,max}$ at RT, as specified by the manufacturer, see 7.3.2.



Key

X time [s]

Y fraction of $I_{dp,max}$ [%]

1 discharge

2 charge

Figure 10 — Profile for cycle life test – Plug-in discharge-rich current profile

Table 16 — Time and current data – Plug-in discharge-rich current profile

Step	Time increment [s]	Time cumulative [s]	Fraction of I_{max} [%]
1	16	16	0
2	28	44	+12,5
3	12	56	+25
4	8	64	–12,5
5	16	80	0
6	24	104	+12,5
7	12	116	0
8	8	124	–12,5
9	16	140	0
10	24	164	+12,5
11	12	176	+25
12	8	184	–12,5
13	16	200	0
14	32	232	+12,5
15	12	244	+ 25
16	24	268	0
17	8	276	–25
18	32	308	0
19	8	316	–50
20	44	360	0

NOTE Because of different time delays and slew rates of various battery testers which will be used, no shorter pulses than 5 s are defined.

In this profile, I_{max} shall be the maximum rated pulse discharge current $I_{dp,max}$ at RT, as specified by the manufacturer, see 7.3.2.

7.7.2.2.4 Conditions

— Ambient: start at RT in a temperature chamber with adequate safety equipment.

— Customer or supplier specified SOC swing range, otherwise 25 % to 35 % SOC range.

— Designated (or comparable) battery system cooling has to operate.

— During cycling, the DUT electronic shall ensure that no cell limits will be exceeded, by achieving voltage limits as specified by the supplier. The current has to be reduced automatically to avoid any abuse operation.

7.7.2.3 Monitoring and data logging

All available voltage and temperature sensor data shall be monitored and logged. The amount of stored data may be reduced by logging only during selected (critical) parts of the test sequences.

Cumulated capacity which corresponds to the delta SOC shall be recorded in order to compare with the SOC value given by the BCU.

7.7.2.4 SOC determination

Due to ageing during the cycling test, a capacity loss is expected. Therefore it is very important to provide a clear procedure to determine the SOC over the whole test period. The rated capacity, determined in 7.1, specifies the range between 100 % SOC (fully charged) and 0 % SOC (fully discharged). For adjustment of the SOC values, the 100 % value shall be taken as basis.

7.7.2.5 End of test criteria

The cycle life test shall be terminated according to any of the following end of test criteria:

— the cycle life test for dynamic discharge applications cannot be performed any longer, e.g. because limits are reached;

— the requirements of the parameter check between the power cycling sequences according to Table 11 step 13 to 29 or Table 14 step 16 to 32 can no longer be fulfilled;

— agreement between supplier and customer.

7.7.2.6 Capacity fade

The change of dischargeable capacity from the beginning-of-life value (measured according energy and capacity test at RT, 7.1) to some later point in time shall be reported periodically as capacity fade. The capacity fade, C_{fade}, shall be expressed as a percentage of the initial BOL capacity (C/3 at RT) as shown in the following equation:

$$C_{\text{fade}} = \left(1 - \frac{C_{\text{rt}}^{t_{\text{x}}}}{C_{\text{rt}}^{t_0}} \right) \times 100\ \% \qquad (2)$$

where

$C_{\text{rt}}^{t_{\text{x}}}$ is the C/3 capacity at current test;

$C_{\text{rt}}^{t_0}$ is the rated C/3 capacity at BOL;

t_{x} is the time of the later C/3 capacity where capacity fade has to be determined;

t_0 is the time of the initial BOL C/3 capacity.

7.7.3 Requirement

The following data shall be reported:

— initial C/3 capacity at RT and –10 °C;

— internal resistances, peak power and OCV versus time from the four-weekly voltage controls at RT;

— C/3 capacity versus cycling time at RT from the four-weekly C/3 capacity determination and at –10 °C from the eight-weekly C/3 capacity determination;

— capacity fade versus cycling time.

8 Reliability tests

8.1 Dewing (temperature change)

8.1.1 Purpose

This test simulates the use of the system/component under high ambient humidity. The failure modes addressed are electrical malfunction(s) caused by moisture (e.g. leakage current caused by a printed circuit board which is soaked with moisture). An additional failure mode can be a breathing effect which transports moisture inside the housing when the air inside the system/components cools down and ambient air with high humidity is drawn into the system/components.

This test applies to battery packs and systems.

8.1.2 Test procedure

Perform the test in reference to IEC 60068-2-30, *Db*, but:

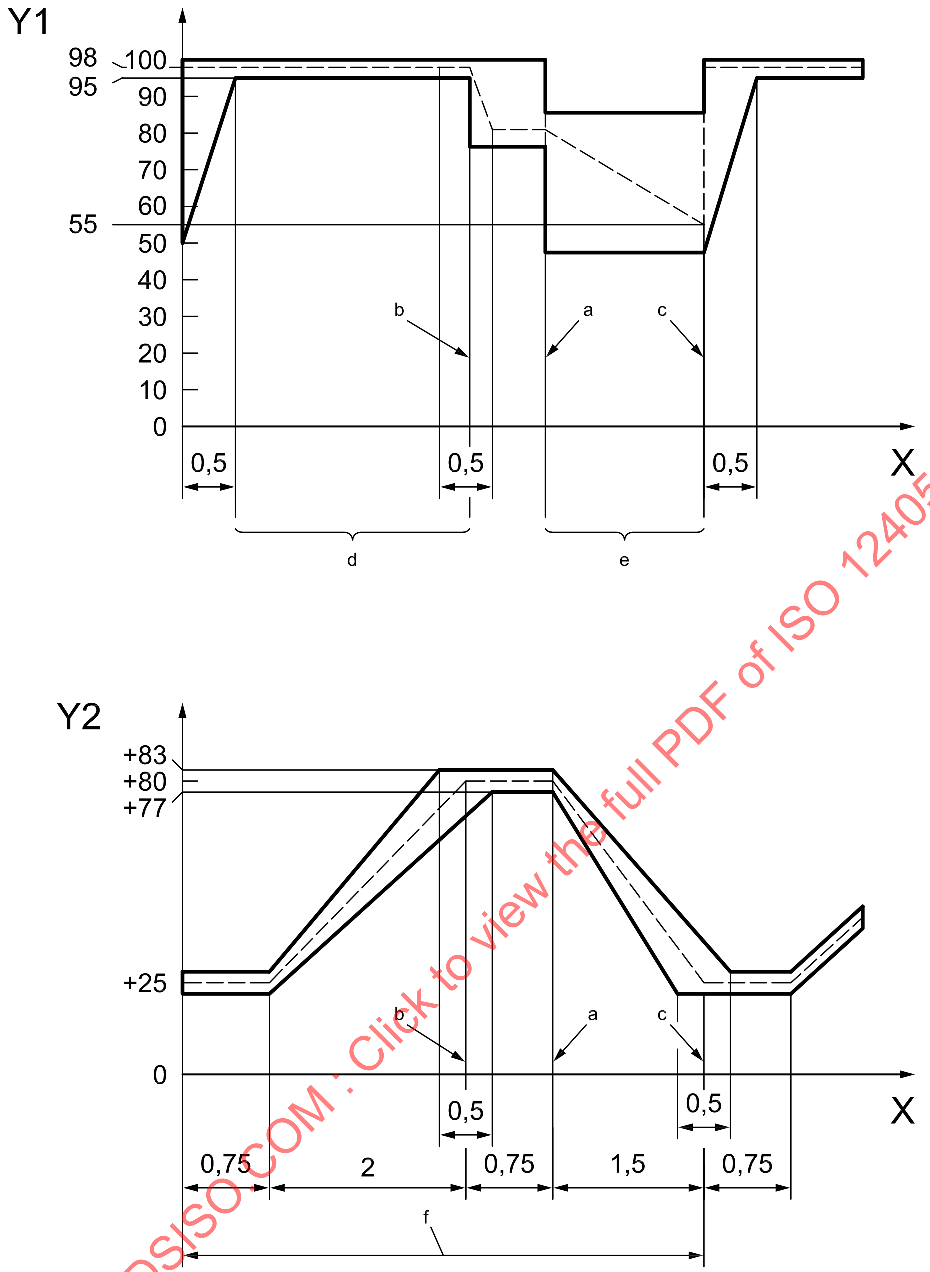
— humidity and temperature profiles according to Figure 11,

— number of cycles is 5.

Use operating mode 2.1 according to ISO 16750-1 during the complete test sequence.

If the temperature of the DUT exceeds the limits given by the supplier, the DUT should be operated in an operating mode as agreed between customer and supplier.

NOTE The temperature and humidity profile is specified to generate dewing affected like in the vehicle environment.



Key

X time [h]

Y1 relative humidity [%]

Y2 temperature [°C]

a start of temperature fall

b end of temperature rise

c recommended set value humidity/temperature

d condensation

e drying

f one cycle

Figure 11 — Dewing cycle

NOTE For detailed test description see ISO 16750-4.

8.1.3 Requirement

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

Measured data shall include:

— isolation resistance between the DUT case and the positive and negative terminals before and after the test.

8.2 Thermal shock cycling

8.2.1 Purpose

Thermal shock cycling is performed to determine the resistance of the DUT to sudden changes in temperature. The DUT undergoes a specified number of temperature cycles, which start at RT followed by high and low temperature cycling. The failure modes addressed are electrical and mechanical malfunction(s) caused by the accelerated temperature cycling.

This test applies to battery packs and systems.

8.2.2 Test

Before thermal shock cycling, the DUT capacity shall be evaluated by performing two standard cycles (SC) according to 6.2. Adjust the SOC with a C/3 discharge to 80 % before starting the thermal shock cycling profile.

With the DUT at 80 % SOC and at RT, contained in a closed volume and with all thermal controls disabled, thermally cycle the DUT with ambient temperature between 85 °C or T_{max} as specified between supplier and customer to −40 °C (the ambient temperature should be measured in close proximity to the DUT). The time to reach each temperature extreme shall be 30 min or less. If it is logistically possible, given equipment limitations and safety considerations, the DUT can be moved between two test chambers each set at the opposite end of the temperature range. The DUT shall remain at each extreme for a minimum of 1 h. A total of five thermal cycles shall be performed. After thermal cycling, inspect the DUT for any damage, paying special attention to any seals that may exist. Verify that control circuitry is operational.

Operating mode shall be continuous monitoring of temperatures and voltages of all available measuring points of the DUT.

After thermal shock cycling, the DUT capacity shall be evaluated by performing two standard cycles (SC) according to 6.2.

Measured data shall include:

— temperatures and voltages of all available measuring points of the DUT during the test;

— isolation resistance between the DUT case and the positive and negative terminals before and after the test;

— C/3 capacity at RT before and after thermal shock cycling test (in each case capacity of second standard cycle).

8.2.3 Requirement

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

8.3 Vibration

8.3.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration. Vibration of the body is random vibration induced by rough-road driving as well as internal vibration of the power train. The main failures to be identified by this test are breakage and loss of electrical contact.

The vibration test is composed of two parts,

— Part 1 of the vibration test procedure is intended to test the behaviour of the overall battery pack or system. Due to the big mass of this DUT the maximum test frequency is limited to 200 Hz, but the vibration test shall be performed in sequence in all three spatial directions.

— Part 2 of the vibration test procedure is intended to test separately the behaviour of the electric and electronic devices with low masses (comparable to electric/electronic devices used in normal vehicle applications) including their mounting devices used in the battery pack or system. This test follows ISO 16750-3 for mounting areas on sprung masses (vehicle body).

This test applies to battery packs and systems.

NOTE This test may be performed using a battery pack sub-system, see 5.1.

8.3.2 Part 1: Battery pack and system

8.3.2.1 Test procedure

The test shall be performed according to IEC 60068-2-64, see Tables 17 to 20, or according to a test profile determined by the customer and verified to the vehicle application.

The given test parameters are valid for DUT designed for mounting on sprung masses (vehicle body) of a vehicle. The DUT shall be mounted on a shaker test bench according to the designed vehicle mounting position and according to the requirements given in IEC 60068-2-47.

The vibration test shall be performed in a sequence of all three spatial directions, if not otherwise agreed between customer and supplier, starting with the vertical direction (Z), followed by the transverse direction (Y) and finally with the longitudinal direction (X).

The mechanical stresses acting on the DUT are specified by a stochastic acceleration – time function with a test duration per spatial direction of 21 h. The test duration per spatial direction can be reduced to 15 h if the test procedure is performed with two identical DUTs, or to 12 h if the test procedure is performed with three identical DUTs. For this, one test spectrum between 5 Hz and 200 Hz is defined for each spatial direction as the desired PSD for the vibration controller (PSD_vertical_Z, PSD_horizontal_transverse_Y, PSD_horizontal_longitudinal_X). If the DUT is designed for a vehicle mounting position below the vehicle passenger compartment, then the reduced spectrum PSD_horizontal transverse_$Y_{Passenger_compartment_bottom}$ according to Table 19 shall be used. In case of any doubt, supplier and customer shall agree which transverse Y profile applies.

Table 17 — Values for PSD_horizontal_longitudinal_X

Frequency [Hz]	**PSD** [g^2/Hz]	**PSD** [$(m/s^2)^2$/Hz]
5	0,012 5	1,20
10	0,03	2,89
20	0,03	2,89
200	0,000 25	0,02
r.m.s.	0,96 g	9,42 m/s^2

Table 18 — Values for PSD_horizontal_transverse_Y

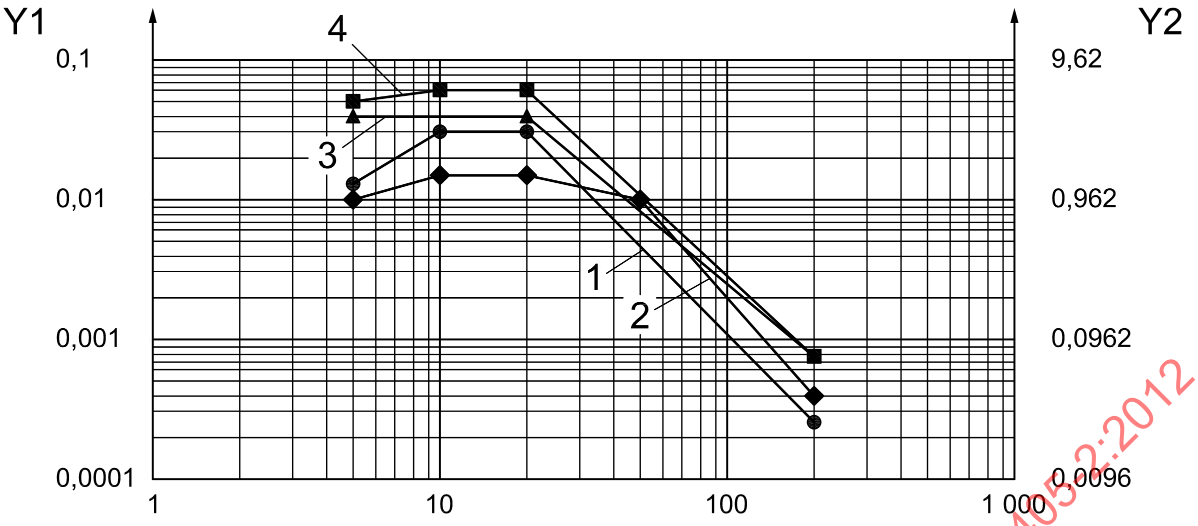
Frequency [Hz]	**PSD** [g^2/Hz]	**PSD** [$(m/s^2)^2$/Hz]
5	0,04	3,85
20	0,04	3,85
200	0,000 8	0,08
r.m.s.	1,23 g	12,07 m/s^2

Table 19 — Values for PSD_horizontal_transverse_$Y_{Passenger_compartment_bottom}$

Frequency [Hz]	**PSD** [g^2/Hz]	**PSD** [$(m/s^2)^2$/Hz]
5	0,01	0,96
10	0,015	1,44
20	0,015	1,44
50	0,01	0,96
200	0,000 4	0,04
r.m.s.	0,95 g	9,32 m/s^2

Table 20 — Values for PSD_vertical_Z

Frequency [Hz]	**PSD** [g^2/Hz]	**PSD** [$(m/s^2)^2$/Hz]
5	0,05	4,81
10	0,06	5,77
20	0,06	5,77
200	0,000 8	0,08
r.m.s.	1,44 g	14,13 m/s^2



Key

X frequency [Hz]
Y1 power density [g^2/Hz]
Y2 PSD [$(m/s^2)^2$/Hz]
1 PSD_horizontal_longitudinal_X
2 PSD_horizontal_transverse_$Y_{Passenger_compartment_bottom}$
3 PSD horizontal transverse Y
4 PSD vertical Z

Figure 12 — PSD spectra for sprung masses (masses mounted on vehicle body)

The following control parameters shall be ensured:

— Delta frequency: 1,25 ± 0,25 Hz

— Inner range of tolerance (warning level): ± 3 dB

— Outer range of tolerance (shut-down level): ± 6 dB

It has to be assumed that especially the battery pack or system design lifetime is affected by temperatures; therefore the vibration testing (test time for each spatial direction) of the battery pack or system shall be superimposed by a temperature profile according to Table 21:

Table 21 — Values for test duration and ambient temperature

Time [min]			Ambient temperature
1 test sample	2 test samples	3 test samples	
0	0	0	RT
105	75	60	T_{min}
420	300	240	T_{min}
525	375	300	RT
700	500	400	T_{max}
1085	775	620	T_{max}
1260	900	720	RT
Σ = 21 h	Σ = 15 h	Σ = 12 h	

T_{min} and T_{max} shall be agreed between supplier and customer. If not defined, the following values shall be used: T_{min} = −40 °C; T_{max} = 75 °C.

Before vibration testing, the DUT capacity shall be evaluated by performing two standard cycles (SC) according to 6.2. Adjust the SOC with a C/3 discharge to 50 % before starting the vibration test profile.

After vibration testing, the DUT capacity shall be evaluated by performing two standard cycles (SC) according to 6.2.

8.3.2.2 Requirement

Breakage and loss of electrical contact shall not occur according to the requirements of the vibration test procedure.

Operating mode shall be with main contactors closed.

The functional status shall be class A (see ISO 16750-1) during operating mode 3.2 as specified in ISO 16750-1, and class C during periods with other operating modes.

Measured data shall include:

— voltage across the positive and negative terminals of the DUT during the test;

— isolation resistance between the DUT case and the positive and negative terminals before and after the test;

— C/3 capacity at RT before and after the test (in each case C/3 capacity of second standard cycle).

8.3.3 Part 2: Electric/electronic devices of battery pack and system

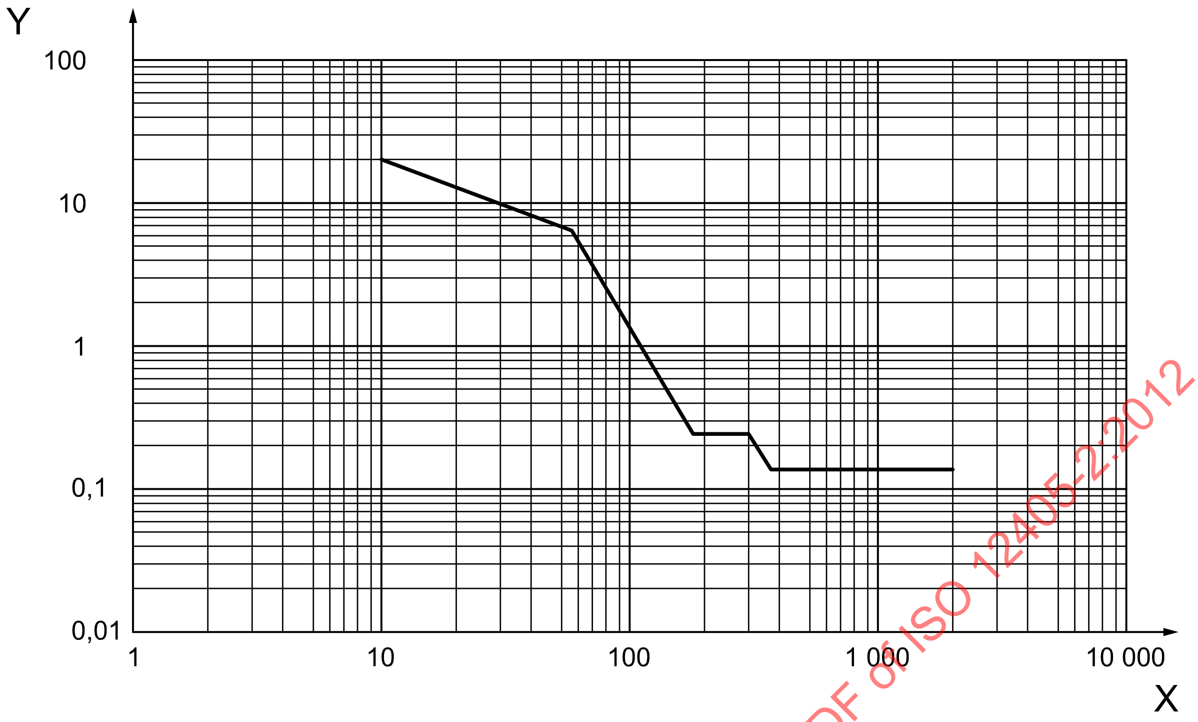
8.3.3.1 Test procedure

The given test parameters are valid for DUT designed for mounting on sprung masses (vehicle body) of a vehicle. If the specific requirement of the vehicle and/or the mounting area differs from those requirements given in the following test procedure, the test shall be performed according to ISO 16750-3 for other mounting areas or according to data from specific operating load measurements on a vehicle.

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

The r.m.s. acceleration value shall be 27,8 m/s^2.

The PSD versus frequency are referred to Figure 13 and Table 22.



Key

X frequency [Hz]

Y1 PSD [(m/s²)²/Hz]

1 discharge

2 charge

Figure 13 — PSD of acceleration versus frequency

Table 22 — Values for PSD and frequency

Frequency [Hz]	**PSD** [(m/s²)²/Hz]
10	20
55	6,5
180	0,25
300	0,25
360	0,14
1 000	0,14
2 000	0,14

8.3.3.2 Requirement

Breakage and loss of electrical contact shall not occur according to the requirements for both parts of vibration test procedures.

The functional status shall be class A (see ISO 16750-1) during operating mode 3.2 as specified in ISO 16750-1, and class C during periods with other operating modes.