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Electrically propelled mopeds and motorcycles — Test specifications and safety requirements for lithium-ion battery systems

Cyclomoteurs et motocycles à propulsion électrique — Spécifications d'essai et exigences de sécurité pour les systèmes de batterie au lithium-ion

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Foreword

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

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

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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 World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 38, *Motorcycles and mopeds*.

Introduction

Lithium-ion based battery systems are an efficient alternative energy storage system for electrically propelled mopeds and motorcycles. The requirements for lithium-ion based battery systems to be used as power source for the propulsion of electrically propelled mopeds and motorcycles are significantly different to those batteries used for consumer electronics or stationary usage.

This document provides specific test procedures for lithium-ion battery packs and systems specifically developed for propulsion of mopeds and motorcycles. 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 mopeds and motorcycles industry.

It enables mopeds and motorcycles manufacturers to choose test procedures to evaluate the characteristics of a battery pack or system for their specific requirements.

Electrically propelled mopeds and motorcycles — Test specifications and safety requirements for lithium-ion battery systems

1 Scope

This document specifies the test procedures for lithium-ion battery packs and systems used in electrically propelled mopeds and motorcycles.

The specified test procedures enable the user of this document to determine the essential characteristics on performance, safety and reliability of lithium-ion battery packs and systems. The user is also supported to compare the test results achieved for different battery packs or systems.

This document enables setting up 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 are selected from the standard tests provided in this document to configure a dedicated test plan.

NOTE 1 Electrically power-assisted cycles (EPAC) cannot be considered as mopeds. The definition of electrically power-assisted cycles can differ from country to country. An example of definition can be found in the EU Directive 2002/24/EC.

NOTE 2 Testing on cell level is specified in IEC 62660 (all parts).

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 13063, *Electrically propelled mopeds and motorcycles — Safety specifications*

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

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 60068-2-52, *Environmental testing — Part 2-52: Tests – Test Kb: Salt mist, cyclic (sodium, chloride solution)*.

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 http://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 and that provides communication between the battery system and other mopeds and motorcycles controllers

3.2
battery pack
energy storage device that includes cells or cell assemblies normally connected with cell electronics, high voltage circuit and over current shut-off device including electrical interconnections, interfaces for external systems (e.g. cooling, high voltage, auxiliary low voltage and communication)

Note 1 to entry: See 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 (e.g. BCU, contactors)

Note 1 to entry: See A.3.1 and A.3.2 for further explanation. Battery system components can also be distributed in different devices within the vehicle.

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

3.5
cell electronics
electronic device that collects and possibly monitors thermal and electrical data of cells or cell assemblies and contains electronic 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 it can be controlled by the BCU.

3.6
energy round trip efficiency
ratio of the net DC energy (W·h discharge) delivered by a DUT during a discharge test to the total DC energy (W·h charge) required to restore the initial SOC by a standard charge

3.7
rated capacity
suppliers 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, discharge cut-off voltage, etc.

3.8
room temperature
RT
temperature of (25 ± 2) °C

3.9
device under test
DUT
battery pack or battery system

3.10
sign of battery current
discharge current is specified as positive and the charge current as negative

3.11
state of charge
SOC
available capacity in a battery pack or system expressed as a percentage of rated capacity

3.12
standard charge for top off
SCH
additional charge which eliminates possible SOC reduction after SCH at RT followed by thermal equilibration at a different temperature

3.13
voltage class A
classification of an electric component or circuit with a maximum working voltage of ≤30 V a.c. or ≤60 V d.c., respectively

Note 1 to entry: For more details, see ISO 6469-3.

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

3.15
maximum working voltage
highest value of a.c. voltage (r.m.s.) or of d.c. voltage which may occur in an electrical system under any normal operating conditions according to the manufacturer's specifications, disregarding transients

3.16
isolation resistance
resistance between live parts of voltage class B electric circuit and the electric chassis as well as the voltage class A system

3.17
rupture
loss of mechanical integrity of the enclosure of the DUT resulting in openings that do not fulfil protection degree IPXXB according to ISO 20653

3.18
explosion
sudden release of energy sufficient to cause pressure waves and/or projectiles that may cause structural and/or physical damage to the surrounding of the DUT

Note 1 to entry: The kinetic energy of flying debris from the battery back or system may be sufficient to cause damage as well.

3.19
fire
continuous emission of flames from a DUT (approximately more than 1 s)

Note 1 to entry: Sparks and arcing are not considered as flames.

3.20
venting
release of excessive pressure from a DUT intended by design

3.21
leakage
escape of liquid or gas from a DUT regardless of venting (pressure release device for cell) or not

3.22
customer
party interested in using the battery pack or system and, therefore, orders or performs the test

EXAMPLE A moped/motorcycle manufacturer.

3.23
supplier
party that provides battery systems and packs

EXAMPLE A battery manufacturer.

3.24
thermal equilibration
DUT achieving the thermal target

3.25
thermal equilibrium
thermal balance of the cell among the DUT

3.26
battery pack subsystem
representative portion of the battery pack

4 Symbols and abbreviated terms

BCU	battery control unit
C	capacity, expressed in ampere-hours (A·h)
*n*C	current rate equal to *n* times the 1 h discharge capacity expressed in ampere (e.g. 5C is equal to five times the 1 h current discharge rate, expressed in A)
DUT	device under test
EODV	end of discharge voltage
$I_{d\ max}$	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
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

5 General requirements

5.1 General conditions

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

— electrical safety design shall be approved according to the requirements given in ISO 13063; and

— necessary documentation for operation and needed interface parts for connection to the test equipment (i.e. connectors, plugs including cooling) 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.

If not otherwise specified, the tests described apply to battery packs/systems. The status of the DUT, e.g. new product, tested or used, shall be agreed upon between customer and supplier before testing. The history of the DUT shall be documented.

If not otherwise specified, before each test the DUT shall be stabilized at the test temperature for a minimum of 12 h and the BCU, if any, shall be switched off. This period may be reduced if the thermal equilibration of the DUT is reached. Thermal equilibration is fulfilled when, after a period of 1 h, the change among all available cell temperature measuring points is lower than 4 °C .

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 %; and

— 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 %; and

— dimensions: ±0,1 %.

All values (time, temperature, current and voltage) shall be recorded at least every 1 % of the estimated discharge and charge time, except if it is noted otherwise in the individual test procedure.

5.2 Tests

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

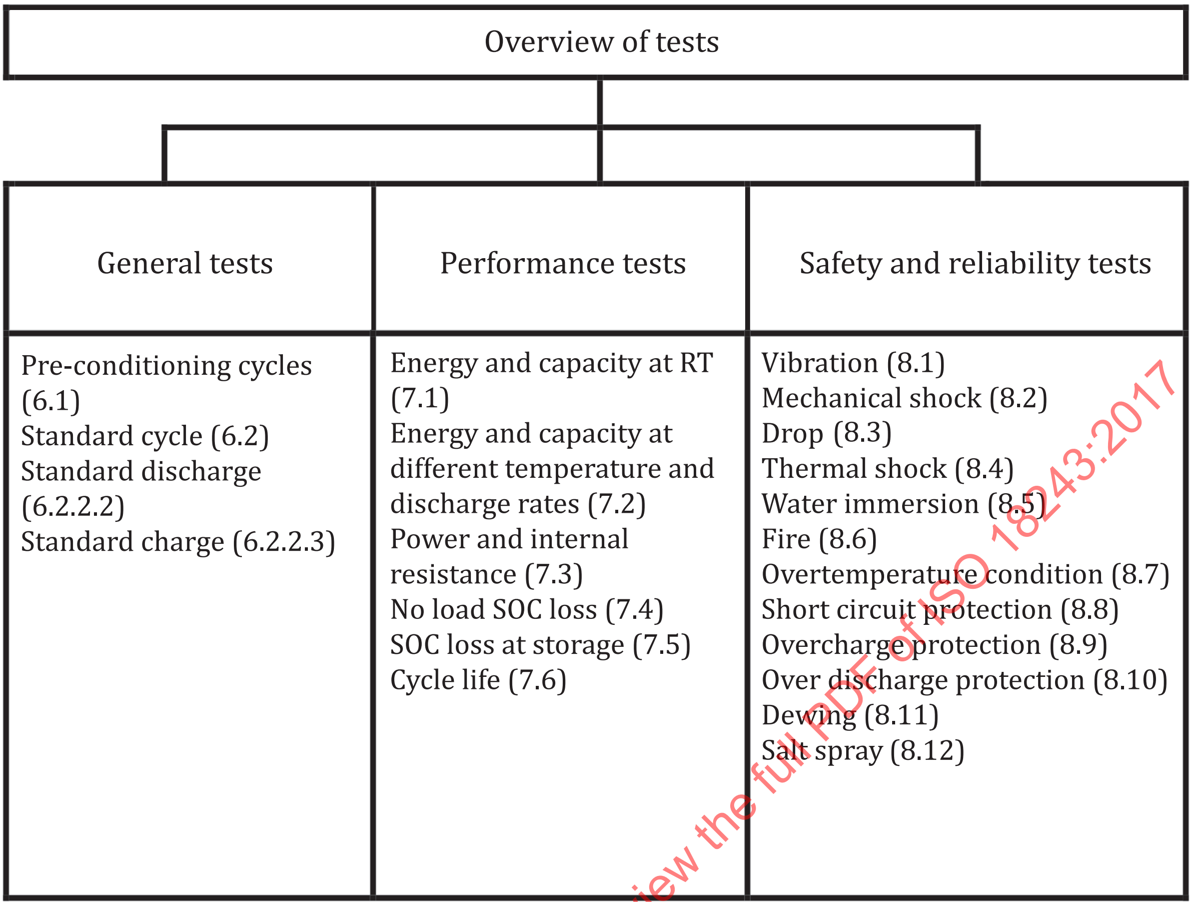

Figure 1 — Overview of the tests

5.3 Test procedure

The test sequence and sample numbers for an individual battery pack or system, or a battery pack subsystem, shall be based on agreement between customer and supplier. The basic suggestion of test procedure is listed in Table 1.

Table 1 — Test procedure

Seq	Test type	Test procedure	Sample SN
1	General tests	Pre-conditioning cycles (6.1)	1#–20#
2		Standard cycle (6.2)	1#–20#
3		Standard discharge (6.2.2.2)	1#–20#
4		Standard charge (6.2.2.3)	1#–20#
5	Performance tests	Energy and capacity at RT (7.1)	1#–20#
6		Energy and capacity at different temperature and discharge rates (7.2)	1#
7		Power and internal resistance (7.3)	2#
8		No load SOC loss (7.4)	3#
9		SOC loss at storage (7.5)	4#
10		Cycle life (7.6)	5#
11	Safety and reliability tests	Vibration (8.1)	6#
12		Mechanical shock (8.2)	7#
13		Drop (8.3)	8#
14		Thermal shock (cycle) (8.4)	9#
15		Water immersion (8.5)	10#
16		Fire (8.6)	11#
17		Overtemperature condition (8.7)	12#
18		Short circuit protection (8.8)	13#
19		Overcharge protection (8.9)	14#
20		Over discharge Protection (8.10)	15#
21		Dewing (8.11)	16#
22		Salt spray (8.12)	17#

5.4 Preparation of the DUT for testing

5.4.1 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 supplier's requirements and according to the given test specification by the test bench equipment. The passive overcurrent protection shall be maintained by the test bench equipment, if necessary via disconnection of the battery pack main contactors. The cooling device can 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, voltage class A and cooling system and BCU 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 test methods

6.1 Pre-conditioning cycles

6.1.1 Purpose

The DUT shall be conditioned by performing some electrical cycles, before starting the tests of Clauses 7 and 8, 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).

6.2 Standard cycle (SC)

6.2.1 Purpose

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

6.2.2 Test procedure

6.2.2.1 General

The 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 voltage limit: According to the specifications given by the supplier.

Rest period after discharge to reach a stable condition: 60 min.

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 in at least 8 h.

Rest period after charge to reach a stable condition:

— 60 min.

7 Performance test

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 3-h discharge capacity is 45 A·h, the discharge rate is 15 A). The 3-h rate (C/3), 1C and 2C are 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 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.

7.1.2 Test procedure

The test shall be performed at RT with the discharge rates C/3, 1C, 2C and, if applicable, 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 RT

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

The SCH procedure shall follow 6.2.2.3.

The standard cycle 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 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.

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 *n*C 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);

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

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

7.2 Energy and capacity at different temperature 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 three different temperatures (40 °C, 0 °C and T min ≤ −10 °C as defined by the manufacturer) 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 3.

Table 3 — Test sequence energy and capacity test at different temperature and discharge rates

Step	Procedure	Ambient temperature
1.1	Thermal equilibration	RT
1.2	SCH	RT
1.3	SC	RT
2.1	Thermal equilibration	40 °C
2.2	SCH for top off	40 °C
2.3	Discharge at C/3	40 °C
3.1	Thermal equilibration	RT
3.2	SCH	RT

Table 3 *(continued)*

Step	Procedure	Ambient temperature
3.3	SC	RT
4.1	Thermal equilibration	40 °C
4.2	SCH for top off	40 °C
4.3	Discharge at 1C	40 °C
5.1	Thermal equilibration	RT
5.2	SCH	RT
5.3	SC	RT
6.1	Thermal equilibration	40 °C
6.2	SCH for top off	40 °C
6.3	Discharge at 2C	40 °C
7.1	Thermal equilibration	RT
7.2	SCH	RT
7.3	SC	RT
8.1	Thermal equilibration	40 °C
8.2	SCH for top off	40 °C
8.3	Discharge at $I_{d\ max}$	40 °C
9.1	Thermal equilibration	RT
9.2	SCH	RT
9.3	SC	RT
10.1	Thermal equilibration	0 °C
10.2	SCH for top off	0 °C
10.3	Discharge at C/3	0 °C
11.1	Thermal equilibration	RT
11.2	SCH	RT
11.3	SC	RT
12.1	Thermal equilibration	0 °C
12.2	SCH for top off	0 °C
12.2	Discharge at 1C	0 °C
13.1	Thermal equilibration	RT
13.2	SCH	RT
13.3	SC	RT
14.1	Thermal equilibration	0 °C
14.2	SCH for top off	0 °C
14.2	Discharge at 2C	0 °C
15.1	Thermal equilibration	RT
15.2	SCH	RT
15.3	SC	RT
16.1	Thermal equilibration	0 °C
16.2	SCH for top off	0 °C
16.3	Discharge at $I_{d\ max}$	0 °C
17.1	Thermal equilibration	RT
17.2	SCH	RT
17.3	SC	RT

Table 3 *(continued)*

Step	Procedure	Ambient temperature
18.1	Thermal equilibration	T_{min}
18.2	SCH for top off	T_{min}
18.3	Discharge at C/3	T_{min}
19.1	Thermal equilibration	RT
19.2	SCH	RT
19.3	SC	RT
20.1	Thermal equilibration	T_{min}
20.2	SCH for top off	T_{min}
20.3	Discharge at 1C	T_{min}
21.1	Thermal equilibration	RT
21.2	SCH	RT
21.3	SC	RT
22.1	Thermal equilibration	T_{min}
22.2	SCH for top off	T_{min}
22.3	Discharge at 2C	T_{min}
23.1	Thermal equilibration	RT
23.2	SCH	RT
23.3	SC	RT
24.1	Thermal equilibration	T_{min}
24.2	SCH for top off	T_{min}
24.3	Discharge at $I_{d\,max}$	T_{min}
25.1	Thermal equilibration	RT
25.2	SCH	RT
25.3	SC	RT

The SCH procedure at the different temperatures shall follow 6.2.2.3.

The 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, 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.

Test steps that are out of maximum current rates specified by the manufacturer for a given temperature shall be omitted.

NOTE 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); and

— 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 mopeds and motorcycles driving operation.

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 suppliers 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 an 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 4 and Figure 2).

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 always maintain the DUT in 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 always maintain the DUT in specified operating conditions.

Table 4 — 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 2 shows an example with a maximum rated pulse discharge current, I_{max}. The discharge current is specified as positive and the charge current as negative. The maximum rated pulse discharge current, I_{max}, for the pulse power characterization profile has to be specified by the supplier.

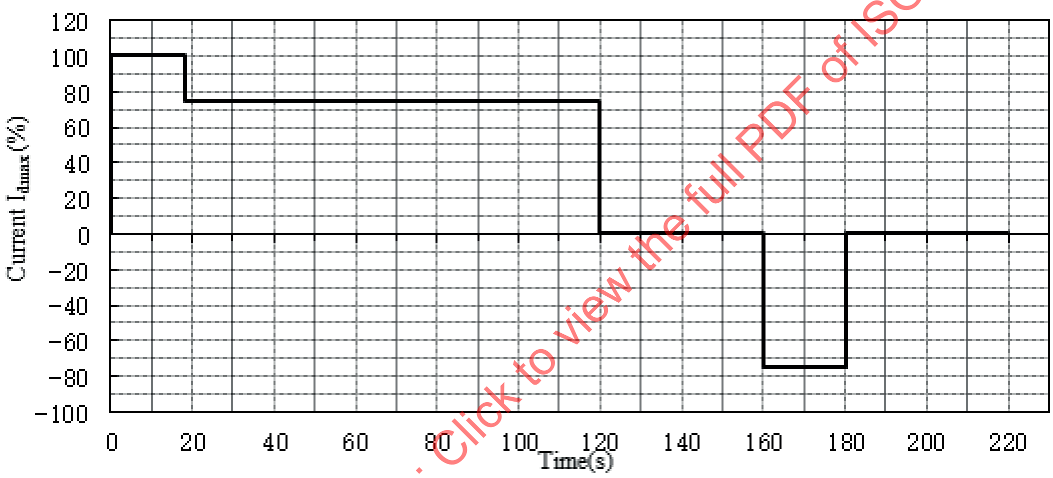

Figure 2 — Pulse power characterization profile — Current

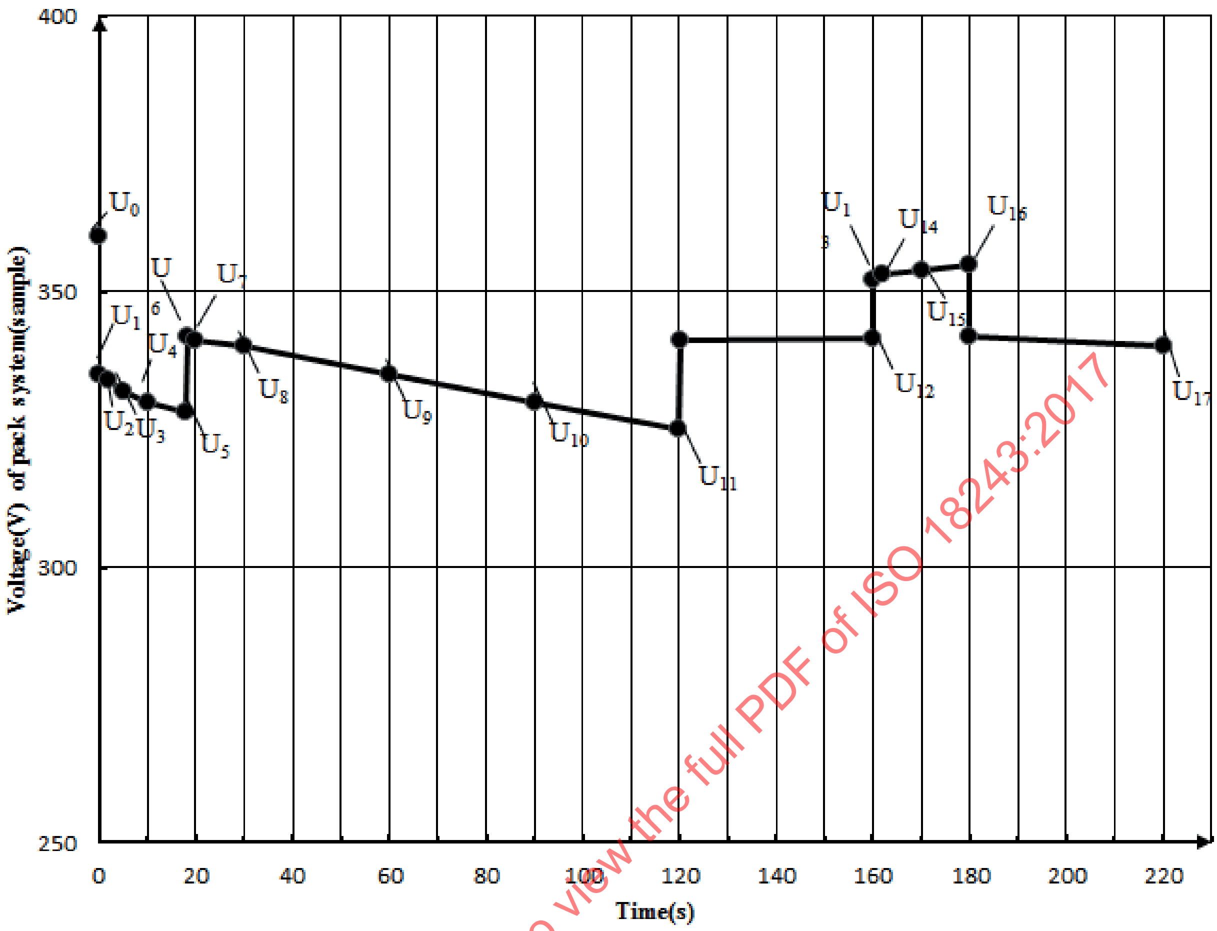

Figure 3 — Pulse power characterization profile — Voltage

NOTE The voltage values in Figure 3 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 5.

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 5 — 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

Table 5 *(continued)*

Time (s)	Current value	Voltage	Current
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}
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 6.

Table 6 — Calculation of resistance and power

Value	Formula	Δt (s)
90 s discharge resistance	$Ri_{90s,\ dch} = (U_0 - U_{10})/I_{10}$	90
120 s discharge resistance	$Ri_{120s,\ dch} = (U_0 - U_{11})/I_{11}$	120
overall discharge resistance	$R_{i\ dch} = (U_{12} - U_{11})/I_{11}$	40
0,1 s charge resistance	$Ri_{0,1s,\ cha} = (U_{12} - U_{13})/I_{13}$	0,1
2 s charge resistance	$Ri_{2s,\ cha} = (U_{12} - U_{14})/I_{14}$	2
10 s charge resistance	$Ri_{10s,\ cha} = (U_{12} - U_{15})/I_{15}$	10
20 s charge resistance	$Ri_{20s,\ cha} = (U_{12} - U_{16})/I_{16}$	20
overall charge resistance	$Ri_{cha} = (U_{16} - U_{17})/I_{17}$	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
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 four different temperatures (40 °C, RT, 0 °C and −10 °C) and shall cover a SOC range of 90 % to 20 % within three steps: 90 % (or supplied by supplier), 50 % and 20 % (or supplied by supplier).

— 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 SCH as provided in 6.2.2.3 for top off and a 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 SCH as provided in 6.2.2.3.

— The SCH is requested in order to condition the DUT to the fully charged states 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 (50 % and 20 %) 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.

The amount of electric charge (A·h) withdrawn during the previous power characterization profile shall 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 SCH shall be performed.

— Data sampling, especially for DUT voltage and current shall be performed with an adequate sampling rate, e.g. 10 ms.

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

Table 7 — Test sequence power and internal resistance test

Step	Procedure	Ambient temperature
1.1	Thermal equilibration	RT
1.2	SCH for top off	RT
1.3	SC	RT
2.1	Thermal equilibration	RT
2.2	SCH for top off	RT
2.3	Pulse power characterization	RT
2.4	SCH	RT
3.1	Thermal equilibration	RT
3.2	SCH for top off	RT
3.3	SC	RT
4.1	Thermal equilibration	40 °C
4.2	SCH for top off	40 °C
4.3	Pulse power characterization	40 °C

Table 7 *(continued)*

Step	Procedure	Ambient temperature
4.4	SCH	40 °C
5.1	Thermal equilibration	RT
5.2	SCH for top off	RT
5.3	SC	RT
6.1	Thermal equilibration	0 °C
6.2	SCH for top off	0 °C
6.3	Pulse power characterization	0 °C
6.4	SCH	0 °C
7.1	Thermal equilibration	RT
7.2	SCH for top off	RT
7.3	SC	RT
8.1	Thermal equilibration	−10 °C
8.2	SCH for top off	−10 °C
8.3	Pulse power characterization	−10 °C
8.4	SCH	−10 °C
9.1	Thermal equilibration	RT
9.2	SCH for top off	RT
9.3	SC	RT
14.1	Thermal equilibration	RT
14.2	SCH for top off	RT
14.3	Pulse power characterization	RT
14.4	SCH	RT

The SCH procedure at the different temperatures shall follow 6.2.2.3.

The SC procedure shall follow 6.2.

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

SCH for top off enables the DUT to be recharged in order to compensate energy losses that may occur during temperature equilibration. Test steps that are out of maximum current rates specified by the manufacturer for a given temperature shall be omitted.

7.3.4 Requirements

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

— discharge power in W 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;

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

— discharge resistance in mΩ 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 in mΩ 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 in V 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; and

— 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 No load SOC loss

7.4.1 Purpose

The purpose of this test is to measure the SOC loss of a battery system if is not used for an extended period of time. This test refers to a scenario that a moped or motorcycle is not driven 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.

7.4.2 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, e.g.

— battery system cell balancing; and

— periodical BCU wake-up activities.

The no load SOC loss rate 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 the fully charged states by a 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, etc.). 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 °C 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, a 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 the fully charged states. 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:	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.

7.4.3 Test sequence

First 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	SCH	RT
1.3	SC	RT
1.4	Rest period at open voltage class B circuit for 168 h	RT
1.5	SC	RT
1.6	Rest period at open voltage class B circuit for 720 h	RT
1.7	SC	RT

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

The remaining capacity will be measured within steps 1.3, 1.5 and 1.7 during the SDCH test, which is the first part of the SC test.

Second 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	SCH	RT
2.3	SC	RT
2.4	Rest period at open voltage class B circuit for 168 h	40 °C (or higher)
2.5	Thermal equilibration	RT
2.6	SC	RT
2.7	Rest period at open voltage class B circuit for 720 h	40 °C (or higher)
2.8	Thermal equilibration	RT
2.9	SC	RT

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

The remaining capacity will be measured within steps 2.3, 2.6 and 2.9 during the SDCH test, which is the first part of the SC test.

7.4.4 Requirement

The remaining C/3 energy and SOC from the initial the fully charged states shall be reported.

The loss of energy and SOC after each rest period shall be expressed as a percentage of the initial the fully charged states.

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.

7.5 SOC loss at storage

7.5.1 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.

7.5.2 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 as well as the service disconnect device, if any.

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.

7.5.3 Test sequence

Table 10 — Test sequence capacity loss at storage

Step	Procedure	Ambient temperature
1	Thermal equilibration	RT
2	SCH	RT
3	SC	RT
4	Discharge at 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	SC for two times	RT

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

The remaining SOC will be measured within step 7 during the SDCH test, which is the first part of the SC test.

7.5.4 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.

7.6 Cycle life

7.6.1 Purpose

Additionally to other ageing factors (i.e. time, temperature), the energy throughput has a significant influence for the life-time of a battery.

For choosing a relevant ageing profile concerning the energy throughput, the real conditions during driving shall be considered. In order to get reliable and significant data for life-time prediction, it is important that the 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 monitoring of the battery system is mandatory, as well as certain rest phases are needed for equilibrium and cell balancing.

This test applies to battery systems only.

7.6.2 Test procedure

See Table 11.

Table 11 — Test sequence cycle life

Step	Procedure	Ambient temperature
1	Thermal equilibration	RT
2	SCH	RT
3	SC	RT
4	Discharge at 1C rate till battery voltage reaches discharge voltage limit defined by the supplier	RT
5	charge at 1C rate to fully charged state	RT
6	Repeat steps 4 to 5 until the discharge capacity is 80 %	RT
7	Thermal equilibration	RT
8	SCH	RT
9	SC	RT

7.6.3 Requirements

The following data shall be reported:

— initial C/3 capacity at RT; and

— 1C capacity versus cycle time.

8 Safety and reliability test

8.1 Vibration

8.1.1 Purpose

Simulates a mechanical load on vibration derived from moped or motorcycle operation which a battery system will likely experience during its life.

8.1.2 Test procedure

The given test parameters are valid for DUT designed for mounting on sprung masses of a moped or motorcycle. 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 a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 min. This cycle shall be repeated 12 times for a total of 3 h for each of three mutually perpendicular mounting positions of the DUT. One of the directions of vibration shall be perpendicular to the terminal face.

The logarithmic frequency sweep for DUT, with a gross mass of not more than 12 kg, is as follows: from 7 Hz, a peak acceleration of 1 gn is maintained until 18 Hz is reached. The amplitude is then maintained at 0,8 mm (1,6 mm total excursion) and the frequency is increased until a peak acceleration of 8 gn occurs (approximately 50 Hz). A peak acceleration of 8 gn is then maintained until the frequency is increased to 200 Hz.

The logarithmic frequency sweep for DUT, with a gross mass of more than 12 kg, is as follows: from 7 Hz, a peak acceleration of 1 gn is maintained until 18 Hz is reached. The amplitude is then maintained at 0,8 mm (1,6 mm total excursion) and the frequency is increased until a peak acceleration of 2 gn occurs (approximately 25 Hz). A peak acceleration of 2 gn is then maintained until the frequency is increased to 200 Hz.

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

8.1.3 Requirements

During the test and for a 1 h post-test observation period, the battery system shall exhibit no evidence of leakage or battery enclosure rupture, fire or explosion and voltage class B DUT shall maintain an isolation resistance of at least 100 Ω/V.

8.2 Mechanical shock

8.2.1 Purpose

Simulates a mechanical load on shock derived from moped or motorcycle operation which a battery system will likely experience during its life.

8.2.2 Test procedure

Adjust the SOC to the fully charged states before starting the mechanical shock test.

DUT with a gross mass of not more than 12 kg shall be secured to the testing machine by means of a rigid mount which will support all mounting surfaces of each test battery. DUT shall be subjected to a half-sine shock of peak acceleration of 150 gn and pulse duration of 6 ms. DUT shall be subjected to three shocks in the positive direction followed by three shocks in the negative direction of three mutually perpendicular mounting positions of the battery for a total of 18 shocks.

DUT with a gross mass of more than 12 kg shall be subjected to a half-sine shock of peak acceleration of 50 gn and pulse duration of 11 ms. Each cell or battery is subjected to three shocks in the positive direction followed by three shocks in the negative direction of each of three mutually perpendicular mounting positions of the cell for a total of 18 shocks.

8.2.3 Requirements

During the test and for a 1 h post-test observation period, the battery system shall exhibit no evidence of leakage or battery enclosure rupture, fire or explosion and voltage class B DUT shall maintain an isolation resistance of at least 100 Ω/V.

8.3 Drop

8.3.1 Purpose

Simulates a mechanical impact load which may occur at an unintended drop during battery exchange or reparation.

8.3.2 Test procedure

Adjust the SOC to the fully charged states before starting the drop test.

Drop DUT freely from height 1 m to the concrete floor, one time for each side.

Or, each sample is to be freely dropped from a height of 1 m on a flat surface made of concrete in the position that is most likely to produce the most adverse result. Each sample is to be dropped three times.

8.3.3 Requirements

During the test and the 6 h post-test observation period, the battery system shall exhibit no evidence of leakage, fire or explosion.

8.4 Thermal shock

8.4.1 Purpose

Simulates a thermal load derived from moped or motorcycle operation which a battery system will likely experience during its life.

8.4.2 Test procedure

Adjust the SOC with a 1C 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} (T_{max} ≥ 60 °C) 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.

8.4.3 Requirements

During the test and the 1 h post-test observation period, the battery system shall exhibit no evidence of leakage or battery enclosure rupture, fire or explosion and voltage class B DUT shall maintain an isolation resistance of at least 100 Ω/V.

8.5 Water immersion

8.5.1 Purpose

Simulates a water immersion which may occur when a moped or motorcycle is flooded.

8.5.2 Test procedure

With the DUT in its normal operating orientation and at full state of charge, immerse the DUT in ambient temperature salt water (5 % by weight NaCl in H_2O) for a minimum of 2 h or until any visible reactions have stopped. The water depth shall be enough to completely submerge the DUT. The DUT may be placed into a tank filled with water or may be placed in an empty tank and water pumped into the tank to fully submerge the DUT.

DUT can be tested by vehicle emulated condition (e.g. battery pack with actual part of vehicle).

8.5.3 Requirements

During the test and the 1 h post-test observation period, the battery system shall exhibit no evidence of fire or explosion.

NOTE If a battery is immersed in conductive water, flammable or toxic gases can be produced. This effect is not unique to lithium-ion battery technology.

8.6 Fire

8.6.1 Purpose

Simulates a thermal load which may occur at a moped or motorcycle fire.

NOTE This test applies to battery packs and systems used on electric mopeds or motorcycles with a passenger compartment.

8.6.2 Test procedure

The flame to which the DUT is exposed shall be obtained by burning commercial fuel for positive-ignition engines (hereafter called "fuel") in a pan. The quantity of fuel poured into the pan shall be sufficient to permit the flame, under free-burning conditions, to burn for the whole test procedure, i.e. at least 25 l/m^2.

Water should be poured at the bottom of the pan to ensure a flat bottom of the pan. The pan dimensions shall be chosen so as to ensure that the sides of the DUT are exposed to the flame. The pan shall therefore exceed the horizontal projection of the DUT by at least 20 cm, but not more than 50 cm. The sidewall of the pan shall not project more than 8 cm above the level of the fuel at the start of the test.

The pan filled with fuel shall be placed under the DUT in such a way that the distance between the level of the fuel in the pan and the bottom of the DUT corresponds to the design height of the DUT above the road surface at the unloaded state of the electric mopeds and motorcycles or if the height is not specified approximately 50 cm or according to the agreement between the customer and the supplier.

During phase C of the test, the pan shall be covered by a screen. The screen shall be placed (30 ± 10) mm above the fuel level measured prior to the ignition of the fuel. The screen shall be made of a refractory material, as prescribed in Annex B. There shall be no gap between the bricks and they shall be supported over the fuel pan in such a manner that the holes in the bricks are not obstructed. The length and width of the frame shall be 20 mm to 40 mm smaller than the interior dimensions of the pan so that a gap of 10 mm to 20 mm exists between the frame and the wall of the pan to allow ventilation. Before the test, the screen shall be at least at the ambient temperature. The firebricks can be wetted in order to guarantee repeatable test conditions.

Phase A: Pre-heating

The fuel in the pan shall be ignited at a distance of at least 3 m from the DUT being tested. After 60 s pre-heating, the pan shall be placed under the DUT by moving either the DUT fixture or the pan.

Phase B: Direct exposure to flame

For 70 s, the DUT shall be exposed to the flame from the freely burning fuel.

Phase C: Indirect exposure to flame

As soon as phase B has been completed, the screen shall be placed between the burning pan and the DUT.

The DUT shall be exposed to this reduced flame for a further 60 s.

Instead of conducting Phase C of the test, Phase B may be continued for additional 60 s.

Phase D: End of test

The burning pan covered with the screen shall be moved back to its original position (phase A). No extinguishing of the DUT shall be done. The DUT shall be observed until such time as the surface temperature of the DUT has decreased to ambient temperature or has been decreasing for a minimum of 3 h.

8.6.3 Requirements

During the test and the post-test observation period, the DUT shall exhibit no evidence of explosion.

8.7 Overtemperature condition

8.7.1 Purpose

Tests the safe behaviour of the battery system in a condition of overtemperature. Validates function of the protection measures against internal overheating, if applicable.

8.7.2 Test procedure

The DUT shall be placed in a convective oven or climatic chamber. The temperature of the DUT shall be set to 50 °C, that is 10 K above the maximum temperature for performance testing (40 °C). A rest period of 2 h or until thermal equilibration has been reached shall be performed. The active cooling device, if any, shall be disabled, if possible.

Perform a discharge and then a charge at the maximum current rate according to the specifications of the manufacturer.

Repeat the discharge and charge cycle until the intervention of the overtemperature protection measure or at the thermal equilibration of the DUT. The DUT's temperature shall be monitored by the measurement devices which are integrated in the DUT by the manufacturer.

NOTE Disconnection of the electrical load is considered an effective protection measure.

8.7.3 Requirements

The DUT shall not exhibit any evidence of leakage, rupture, fire or explosion.

8.8 Short circuit protection

8.8.1 Purpose

The purpose of the short circuit protection test is to check the functionality of the overcurrent protection device.

This device shall interrupt the short circuit current in order to prevent the DUT from further related severe events caused by a short circuit current.

8.8.2 Test procedure

The DUT shall be at RT, fully charged and under normal operating conditions (main contactors are closed, battery systems are controlled by the BCU). An appropriately sized conductor of 20^{+0}_{-10} mΩ shall be used to apply a “hard short” in less than 1 s for 10 min or until another condition occurs that prevents completion of the test (e.g. component melting). The test shall be performed with integrated, passive and non-passive short circuit protection devices operational.

After the DUT has been shorted as described above, the observation of the DUT shall be continued for 2 h.

All functions of the DUT shall be fully operational as designed during the test. At pack level, the overcurrent protecting device (e.g. fuse) shall interrupt the short circuit current. At system level, the short circuit current shall be interrupted by the overcurrent protecting device (e.g. fuse) and/or by an automatic disconnect by the main contactors.

Data sampling, especially for DUT voltage and current, shall be performed with an adequate sampling rate, e.g. 0,1 ms for evaluation of the current shut-off function and the real short circuit current peak.

8.8.3 Requirements

During the test, the battery system shall exhibit no evidence of leakage, rupture, fire or explosion. The voltage class B DUT shall maintain an isolation resistance of at least 100 Ω/V.

8.9 Overcharge protection

8.9.1 Purpose

The purpose of the overcharge protection test is to check the functionality of the overcharge protection function. This function shall interrupt the overcharge current in order to prevent the DUT from any further related severe events caused by an overcharge current.

8.9.2 Test procedure

The DUT shall be at RT, fully charged and under normal operating conditions with the cooling system operating (main contactors are closed, battery system shall be controlled by the BCU). The test shall be performed with integrated, passive circuit protection devices operational. Active charge control shall be disconnected or disabled.

— The DUT shall be charged at a constant current rate which shall be agreed upon by supplier and customer. The recommended constant charge current should be 2C.

— The upper limit for the power-supply voltage should be set not to exceed 20 % of the maximum battery system voltage.

— Charging shall be continued until the DUT interrupt the charging by an automatic disconnect of the main contactors or electronic switches (e.g. transistors in power electronics).

— The overcharge test shall be terminated if the SOC level is above 130 % or cell temperature levels are above 55 °C. Limits for SOC and DUT cell temperature levels for terminating the overcharge protection test may be agreed between supplier and customer.

Data acquisition/monitoring shall be continued for 1 h after charging is stopped.

All functions of the DUT shall be fully operational as designed during the test.

Data sampling, especially for DUT voltage and current, shall be performed with an adequate sampling rate, e.g. 100 ms for evaluation of the current shut-off function.

Directly after the termination of charging, a SC shall be conducted, if not inhibited by the DUT.

8.9.3 Requirements

The BCU shall interrupt the overcharge current by an automatic disconnect of the main contactors or electronic switches in order to prevent the DUT against further related severe effects.

During the test, the battery system shall exhibit no evidence of leakage or battery enclosure rupture, fire or explosion. The voltage class B DUT shall maintain an isolation resistance of at least 100 Ω/V.

8.10 Over discharge protection

8.10.1 Purpose

The purpose of the over discharge protection test it is to check the functionality of the over discharge protection function. This device shall interrupt the over discharge current in order to prevent the DUT from any further related severe events caused by an over discharge current.

8.10.2 Test procedure

The DUT shall be at RT, fully charged and under normal operating conditions (main contactors are closed, battery system are controlled by the BCU). The test shall be performed with integrated, passive circuit protection devices operational. Active discharge control shall be disconnected or disabled.

— Perform a SDCH. If the normal discharge limits are reached, discharging with C/3 rate shall be continued.

— Discharging shall be continued until the DUT interrupt the discharging by an automatic disconnect of the main contactors or electronic switches (e.g. transistors in power electronics).

— The discharge test shall be terminated manually if 25 % of the nominal voltage level or a time limit of 30 min after passing the normal discharge limits of the DUT have been achieved. Values for time and voltage limits for terminating the over discharge protection test may be agreed between supplier and customer.

NOTE Nominal voltage is the voltage given by the supplier as the recommended operating voltage of their battery system. Voltage depends on chemistry, cell numbers and arrangement of cells.

Data acquisition/monitoring shall be continued for 1 h after discharging is stopped.

All functions of the DUT shall be fully operational as designed during the test.

Data sampling, especially at normal discharge limits and beyond for DUT voltage and current, shall be performed with an adequate sampling rate, e.g. 100 ms for evaluation of the current shut-off function.

Directly after the termination of charging, a SC shall be conducted, if not inhibited by the DUT.

8.10.3 Requirements

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.

8.11 Dewing

8.11.1 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.

8.11.2 Test procedure

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

— humidity and temperature profiles according to Figure 4; and

— number of cycles: 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 1 The temperature and humidity profile is specified to generate dewing affected like in the vehicle environment.

NOTE 2 For detailed test description, see ISO 16750-4.

8.11.3 Requirements

All functions of the device/system perform as designed during and after the test.

Measured data shall include

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