INTERNATIONAL STANDARD

ISO 6469-1

Third edition
2019-04

AMENDMENT 1
2022-11

Electrically propelled road vehicles — Safety specifications —

Part 1: Rechargeable energy storage system (RESS)

AMENDMENT 1: Safety management of thermal propagation

Véhicules routiers électriques — Spécifications de sécurité —

Partie 1: Système de stockage d'énergie rechargeable (RESS)

AMENDEMENT 1: Management de la sécurité de la propagation thermique

Reference number
ISO 6469-1:2019/Amd.1:2022(E)

Foreword

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

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

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

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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

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

A list of all parts in the ISO 6469 series can be found on the ISO website.

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

Electrically propelled road vehicles — Safety specifications —

Part 1: Rechargeable energy storage system (RESS)

AMENDMENT 1: Safety management of thermal propagation

Introduction

Insert a new clause “Introduction” as follows:

> With the rapid development of the electric vehicle industry, its core component, the rechargeable energy storage system (RESS), has increasingly attracted attention, especially the safety requirements of RESS have raised a large interest within the public. This document specifies the general safety requirements for the RESS of electrically propelled road vehicles.
>
> This document also focuses on the safety performance of the lithium-ion battery. One central safety issue for lithium-ion battery systems is the potential for propagation of a thermal runaway event due to a cell thermal failure. For this purpose, this document provides methods for testing thermal runaway risk mitigation to support the development of vehicle and system safety concepts.
>
> The document primarily provides a tool kit for vehicle and RESS manufacturers to evaluate their product safety in terms of thermal propagation. It should enable RESS and/or vehicle manufacturers to get a deeper knowledge of the system behaviour in case of an internal failure of a single cell. Combined tests on cell and system level based on this document will provide comparable results about the RESS safety.
>
> Since it does not contain neither pass or fail criteria for thermal propagation, it is not foreseen to be used for homologation purposes.

Scope

Add the following paragraph after the first paragraph.

> Specifically, for lithium-ion based RESS, this document specifies demonstration methods for thermal runaway risk mitigation in case of a cell failure leading to an internal short circuit, including the collection of associated data. It also specifies a selection of different test methods for thermal propagation. The selected tests can be carried out at vehicle level or for RESS and RESS subsystem if appropriate.

Terms and definitions

Add the following additional terminological entries in Clause 3:

3.31
functional unit
entity of hardware or software, or both, capable of accomplishing a specified purpose

[SOURCE: ISO/IEC 2382:2015, 2121310, modified — Notes to entry were removed.]

3.32
internal short circuit
isolation failure inside a cell

Note 1 to entry: Formation of internal short circuits in a single cell may have different causes. The severity of the internal short circuit depends on the nature of the short and what parts of the cell that are involved. Some examples of potential causes of internal short circuit to consider are listed below:

— manufacturing defect involving foreign object debris (i.e. particles deposited on the electrode surfaces during cell manufacturing);

— manufacturing defect due to misalignment of electrode active material and separator;

— separator pinholes and creasing;

— separator shrinkage;

— electronically conductive burrs;

— current collector insulation flaws;

— lithium metal deposition at charging due to intercalation limitations;

— copper corrosion and formation of copper dendrites during cell operation;

— mechanical deformation of the cell, e.g. denting of the cell packaging during manufacture or deformation of the electrode coil or stack resulting from cycling.

3.33
operational design domain
specific operating domain(s) in which the RESS (3.22) is designed to operate, including but not limited to voltage/SOC (3.26) range, current range, temperature range, environmental conditions, and other domain constraints

3.34
safety case for thermal propagation of the RESS
argument that the safety requirements for the RESS (3.22) are complete and satisfied by evidence compiled from the work product of the safety activities during development

Note 1 to entry: Safety case for *thermal propagation* (3.37) of the RESS means in this document that a logical and hierarchical set of work products that describe risks in terms of hazards presented by the RESS in case of an *internal short circuit* (3.32) and the subsequent thermal energy release within the RESS, and which sets expectations and guidance for future performance, if hazards are controlled successfully.

3.35
target cell
cell in which *thermal runaway* (3.38) is initiated

3.36
thermal event
condition (event which occurs) when the temperature within RESS (3.22) rises significantly or is higher than the maximum operating temperature (3.17) as defined by the supplier (3.27) or customer (3.6)

Note 1 to entry: Depending on the situation (e.g. amount of heat generation compared to heat dissipation) a thermal event may or may not lead to a *thermal runaway* (3.38).

3.37
thermal propagation
transfer of thermal energy generated from *thermal runaway* (3.38) of a single cell to adjacent cells, which results in the thermal runaway of other cells in a RESS (3.22) or any assembly of RESS components

3.38
thermal runaway
heat generation caused by uncontrolled exothermic reactions inside the cell

Clause 5

Add a new subclause after 5.6 as follows:

5.7 Thermal propagation requirements

5.7.1 General

Thermal propagation requirements apply only to a lithium-ion RESS or RESS subsystem used for the propulsion of electric vehicles. Internal short circuit is a condition that can cause thermal runaway in a cell with subsequent thermal propagation in a RESS or RESS subsystem and which is not considered in other standards. Internal short circuit can be caused by contamination through the manufacturing process, by several events during operation and by aging (see 3.32).

The variety of lithium-ion technologies and the different cell construction types do not allow the definition of one single test method that covers all conditions in a safe, comparable, and reproducible way. This document provides three approaches to evaluate safety performance against thermal propagation for a RESS or RESS subsystem.

5.7.2 Safety performance of RESS

Safety performance of a RESS or RESS sub-system shall be considered by one of the following approaches:

1) demonstrating system robustness against a thermal failure of one cell to limit or withstand propagation effects by choosing test methods as specified in 6.7;

2) employing appropriate detection systems to identify early markers indicating a latent fault in a cell and demonstrate risk mitigation by the system safety approach detailed in Clause 7.

Clause 6

Add the following subclauses after 6.6 as follows:

6.7 Thermal propagation test

6.7.1 General

This subclause provides test methods to demonstrate the behaviour of a RESS or RESS subsystem in case of internal short circuit or thermal runaway caused by failure of a single cell. It also provides the test methods to generate measurement data which can be used to evaluate the safety performance of a RESS or RESS subsystem. The test method should be selected according to the intended test purpose and the possibilities for implementing the trigger method. Installation of a second trigger source may be performed by the test agency but is not required. A guidance for method selection based on cell type and test cases is given in Table 9.

Table 9 — Guidance for method selection

Trigger method	Applicable cell type (limitations provided in relevant clauses)	Application at RESS subsystem level	Application at RESS level	Application at vehicle level	Remarks
Internal heater	Any cell type	Yes	Yes	Yes	Cell manufacture is the only one to be able to introduce the internal heater inside the cell before electrolyte filling.
Localized rapid external heating	Any cell type	Yes	Yes	Yes	Heating element parameter may vary depending on different battery chemistries or cell type choices
Nail penetration	Any cell type	Yes	Yes	Yes	This trigger method cannot be applied to any position in a RESS or RESS subsystem. Can only be applied to the cells located in the outer perimeter of the pack.

NOTE 1 All trigger methods have intrinsic limitations and are state-of-the-art. Additional trigger methods can be developed as appropriate.

NOTE 2 These test methods are developed for lithium-ion RESS and vehicles using such RESS but are also applicable to other battery chemistries and future electric vehicle energy storage technologies and lithium-ion technology for other applications/industries. Using these methods outside of existing lithium-ion battery chemistries or manufacturing methods for electric vehicles, requires further validation to determine the suitability of the method is necessary.

If not otherwise specified, the tests described apply to the RESS or RESS subsystem referred to as device under test (DUT) in the following text. All methods utilize the initiation of thermal runaway in a target cell.

6.7.2 Target cell selection

For target cell selection, the number of adjacent cells, cell packaging, and the distance between cells in proximity to the potential target cell shall be considered. Installation of a trigger for the chosen target cell shall not impede the functionality of the original cell or RESS design and its safety features, such as venting, cooling, battery management system, gas permeability, spacing between cells or other components and thermal barriers.

In the field, a single cell thermal runaway may occur in any cell location within the RESS. For externally applied triggers, force may be required to maintain the method in proximity to the target cell and this may dictate the choice of the target cell. Target cell selection should follow a worst-case scenario in terms of thermal propagation.

Examples of conditions to consider are:

— thermal couplings to other cells and to RESS cooling mechanisms;

— thermal insulation around cells;

— geometrical aspect of electrical configuration, e.g. series or parallel connections;

— venting paths inside the RESS;

— configuration of battery management sensors and sampling rate.

Determination of the worst-case scenario may require preliminary tests, calculations or analysis, considering RESS or RESS subsystem design, cell capacity/chemistry/designs, or cooling system.

The selection of a single cell within the DUT depends on the chosen trigger method and the RESS design and shall be agreed between the customer and supplier.

If the intended application scenario is deemed not to have been covered by the tests, then repeating the test procedure with cells in different locations that represent the likely thermal environments and relationships within the RESS may be considered.

NOTE Placing the chosen trigger between battery cells using the existing RESS construction is sufficient but placing the trigger on an edge cell requires additional support structure and forces to maintain adequate contact between the target cell and trigger.

6.7.3 Test conditions

The test is conducted in either a suitable indoor or an outdoor environment. In case of outdoor testing there shall be no precipitation for the duration of the test. Immediately prior to the test commencing, wind speed shall be measured at a location which is no more than 5 m from the DUT and the average wind speed over 10 min shall be less than 28 km/h. It shall be ensured that the results are not affected by gusts of wind. Gusts shall not exceed 36 km/h when measured over a period of 20 s. Test set up should consider the impact of features such as shielding screens or walls which may create excessive funnelling affects during test execution.

The test should be carried out under the conditions as described in 6.1 with the following exceptions:

— charge the DUT to maximum permissible SOC from the battery management system, or a specific value of SOC as agreed between the customer and supplier;

— maintain the RESS temperature between 18 °C to maximum permissible operating temperature;

— maintain a humidity between 10 % and 90 %;

— maintain the atmospheric pressure between 86 kPa – 106 kPa.

For test procedure on vehicle or RESS level, necessary function of the thermal management, battery management and any other battery control systems, shall be operational during the test. For guidance for thermal cooling power estimation see Annex E.

In addition to those presented previously in this subclause, the following conditions should be met for this method:

— to ensure that the DUT is tested at the appropriate SOC according to this subclause, preconditioning of the DUT should be performed as follows

— discharge the DUT at a constant current of 0,2 It A, down to the specified final voltage

— charge the DUT to test SOC according to the method specified by the manufacturer.

NOTE 1 Charging and discharging currents for the tests are based on the value of the rated capacity (Cn Ah). These currents are expressed as a multiple of It A, where: It A = Cn Ah/1 h (see IEC 61434).

NOTE 2 The RESS which cannot be discharged at a constant current of 0,2 It A can be discharged at the current specified by manufacturer.

6.7.4 Evidence criteria of thermal runaway occurrence in target cell

6.7.4.1 Evidence criteria of thermal runaway occurrence in the target cell and other cells

For battery cells with an energy density of less than 130 Wh/kg, evidence of occurrence for thermal runaway during propagation test is provided if one of the following sets of criteria is met and last more than 3 s:

— temperature rise dT/dt >1 K/s and temperature exceeding the thermal runaway onset temperature determined by the cell manufacturer;

or

— temperature exceeding the thermal runaway onset temperature determined by the cell manufacturer with a rapid and distinct voltage drop;

or

— temperature exceeding the thermal runaway onset temperature determined by the cell manufacturer with venting gas or smoke release at least one post disassembly analysis criteria in 6.7.4.2;

or

— temperature rise dT/dt > 1 K/s and venting gas or smoke release and rapid and distinct voltage drop.

For battery cells with an energy density equal to or greater than 130 Wh/kg, evidence of occurrence for thermal runaway during propagation test is provided if one of the following sets of criteria is met and last more than 0,5 s:

— temperature rise dT/dt >15 K/s and temperature exceeding the thermal runaway onset temperature determined by the cell manufacturer;

or

— temperature exceeding the thermal runaway onset temperature determined by the cell manufacturer with a rapid and distinct voltage drop;

or

— temperature exceeding the thermal runaway onset temperature determined by the cell manufacturer with venting gas or smoke and at least one post disassembly analysis criteria in 6.7.4.2;

or

— temperature rise dT/dt > 15 K/s with venting gas or smoke release and a rapid and distinct voltage drop.

NOTE The energy density of a cell is calculated according to IEC 62660-1:2018, 7.6.3.1.

Rapidly changing technologies will require adjustment of the above given parameters, because the parameter 130 Wh/kg to distinguish large or small energy densities of cells has been determined from existing data.

6.7.4.2 Post-test disassembly analysis observations

The following indicators can be considered as supportive evidence of occurrence for thermal runaway:

— occurrence of ejected solid material;

— failure of the BMS or signal faults (if the BMS is still active). Logged faults in the BMS shall be analysed. Thermal runaway indicators shall be specified and documented if required.

The following indicators are post-analysis criteria as evidence of whether a thermal runaway has occurred in the target cell and whether this has resulted in thermal propagation in the RESS or RESS subsystem:

— mass loss greater than its electrolyte mass of the initiated cell;

— RESS or cell rupture;

— RESS deformation;

— material formation indicating high temperatures (e.g. molten and re-solidified aluminium or copper);

— specific reaction products such as e.g. metallic nickel or cobalt, lithium-aluminium oxide;

— current collector foil absence (partial or total);

— thermal decomposition of polymer materials, e.g. separator, isolation material.

6.7.5 Data recording and measurement

6.7.5.1 General advice

Unless otherwise specified in the test methods, the information, documents and data as listed in 6.7.5 shall be provided. Measurement accuracy mentioned in this document shall apply.

6.7.5.2 Recorded data and measurements

The following information shall be recorded during the test, during the observation period and shall be presented in the test report.

All data measurement systems shall be referenced to the same starting time and shall be recorded for an observation period of at least 1 h.

At the RESS and RESS subsystem level the following information shall be recorded:

— identification of test method, chosen trigger method and description of test setup used;

— test conditions (e.g. ambient temperature, SOC, other pre-conditioning parameters);

— battery management system live-data, if available (e.g. single cell voltages, temperatures, isolation faults, other warnings) recorded at a rate that matches the systems' maximum output rate;

— temperature of the target cell [°C];

— temperature of one adjacent cell (if possible);

— independent measurement of DUT voltage as a function of time and if possible, include the BMS pack voltage for comparison;

— voltage of the target cell (if possible);

— video and audio recording including indication of a time stamp of any observable system state change during test (such as defined in 6.7.5.3);

— condition of DUT at the end of test supported by photographs (before and after test) or video;

— temperature of vented gas [°C] exiting the RESS;

— attach thermocouples, not only on the initiation module, but also on the surfaces of adjacent modules, if possible, to observe thermal propagation between modules;

— additional temperature measurement with distributed sensors at the battery surface and at the venting port (if applicable);

— at the end of the test measure the isolation resistance on RESS or RESS subsystem level.

At the vehicle level, the information recorded shall be the same as the RESS level in addition to:

— warning indications or alarms to vehicle occupants.

The following data may be provided as additional information:

— infrared temperature video,

— weight loss of target cell,

— multi-gas measurement inside the vehicle for relevant flammable and toxic gases e.g. CO, H_2, CH_4 and VOCs levels by agreement between customer and supplier. In that case, the measurement method and result shall be reported.

NOTE It is possible to stop the test before the observation period at any time for the safety of personnel and test facilities.

6.7.5.3 Test events and outcome description

During the test, observation of at least the occurrences of the following events should be noted:

— deformation,

— venting,

— leakage,

— smoking,

— rupture,

— fire,

— explosion.

Table 10 can be used for guidance to report the test outcome.

Table 10 — Possible test outcomes

Scenario	Description	Effect
0	Target cell was not triggered to thermal runaway by the chosen trigger.	
1	Target cell thermal runaway was successfully initiated by chosen trigger method.	There is no thermal event of target cell. System controls and mitigations have stabilized the cell.
2	Target cell thermal runaway was successfully initiated by chosen trigger method.	Thermal runaway occurs in target cell, but there is no propagation to adjacent cells.
3	Target cell thermal runaway was successfully initiated by chosen trigger method. Propagation is observed.	Target cell is destroyed by thermal runaway. Propagation occurs in adjacent cells but does not spread beyond cell-block or module.
4	Target cell thermal runaway was successfully initiated by chosen trigger method. Propagation is observed.	Target cell is destroyed by thermal runaway. Propagation occurs in adjacent cells, cell-blocks or modules but is arrested so that no full pack thermal propagation occurs.

Table 10 *(continued)*

Sce-nario	Description	Effect
5	Target cell thermal runaway was successfully initiated by chosen trigger method. Propagation is observed.	Target cell is destroyed by thermal runaway. Propagation occurs in adjacent cells, cell-blocks or modules but is not arrested so that full pack thermal propagation occurs.

6.7.6 Triggering of the DUT through an internal heater

6.7.6.1 Introduction and method specification

This test method relies on an internal, localized short circuit inside the cell created by a local heater. The purpose of this test is to create a thermal runaway through the creation of a hole in the separator of the triggered cell. The hole comes from the local melting of the separator induced by the local heater.

6.7.6.2 Test description

6.7.6.2.1 Trigger method description

The heater is a resistor made of a tungsten flat spiral (Figure 5). The coil is wrapped in one layer of separator with similar melting temperature as the cell separator.

The important parameters of the resistor heater are

— thickness of heating filament: see Figure 5,

— resistance: (200 ± 5) mΩ,

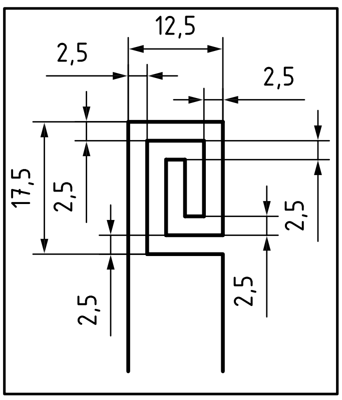
— heating power: from 50 watts to 200 watts between 10 s and 120 s to the cell,

— the entire heating area shall be located on the separator.

The resistance, power and duration shall be adjusted according to the electrochemistry and the size of the cell.

NOTE Energy is only released in the tungsten portion of the device since the external leads do not generate significant heat and, therefore, this additional energy does not influence the outcome of the test.

Dimensions in millimetres



NOTE The wire diameter is usually 0,1 mm to 0,3 mm.

Figure 5 — Example of an internal heater flat spiral of tungsten

6.7.6.2.2 DUT preparation