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Superconductivity –
Part 14: Superconducting power devices – General requirements for characteristic tests of current leads designed for powering superconducting devices

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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CONTENTS

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International Standard IEC 61788-14 has been prepared by IEC technical committee 90: Superconductivity.

The text of this standard is based on the following documents:

FDIS	Report on voting
90/244/FDIS	90/250/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 61788 series, published under the general title *Superconductivity,* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this standard may be issued at a later date.

INTRODUCTION

Current leads are indispensable components of superconducting devices in practical uses such as MRI diagnostic equipment, NMR spectrometers, single crystal growth devices, SMES, particle accelerators such as Tevatron, HERA, RHIC and LHC, experimental test instruments for nuclear fusion reactors, such as ToreSupra, TRIAM, LHD, EAST, KSTAR, W7-X, JT-60SA and ITER, etc., and of advanced superconducting devices in the near future in practical uses such as magnetic levitated trains, superconducting fault current limiters, superconducting transformers, etc.

The major functions of current leads are to power high currents into superconducting devices and to minimize the overall heat load, including heat leakage from room temperature to cryogenic temperature and Joule heating through current leads. For this purpose, current leads are dramatically effective for lowering the overall heat load to use the high temperature superconducting component as a part of the current leads.

On the other hand, the current lead technologies applied to superconducting devices depend on each application, as well as on the manufacturer's experience and accumulated know-how. Due to their use as component parts, it is difficult to judge the compatibility, flexibility between devices, convenience, overall economical efficiency, etc of current leads. This may impede progress in the growth and development of superconducting equipment technology and its application to commercial activities, which is a cause for concern.

Consequently, it is judged industrially effective to clarify the definition of current leads to be applied to superconducting devices and to standardize the common characteristic test methods in a series of general rules.

SUPERCONDUCTIVITY –

Part 14: Superconducting power devices – General requirements for characteristic tests of current leads designed for powering superconducting devices

1 Scope

This part of IEC 61788 provides general requirements for characteristic tests of conventional as well as superconducting current leads to be used for powering superconducting equipment.

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.

IEC 60050-815:2000, *International Electrotechnical Vocabulary* (IEV) – *Part 815: Superconductivity*

IEC 60071-1, *Insulation coordination – Part 1: Definitions, principles and rules*

IEC 60137, *Insulated bushings for alternating voltages above 1 000 V*

3 Terms and definitions

For the purposes of this document, the terms and definitions contained in IEC 60050-815:2000 as well as the following terms and definitions apply:

3.1
current lead
power lead
conductor to introduce electric current into a device with an insulation and a cooling channel especially when leading from room temperature to cryogenic temperature

[IEV 815-06-47]

3.2
normal conducting current lead
conventional current lead
current lead made only of a normal conducting section

3.3
superconducting current lead
current lead containing a superconducting section

NOTE A superconducting current lead consists of a normal conducting section from room temperature to intermediate temperature and a superconducting section from intermediate temperature to cryogenic temperature. In this standard, the superconducting section is mostly made by a high temperature superconductor (HTS).

3.4
non-gas cooled type current lead
current lead cooled by conduction cooling method

3.5
gas-cooled type current lead
current lead cooled by a cooling gas

NOTE In some cases, the gas cooling is made between cooling via gas flow inside the leads and (additional) convection cooling on the outside surface.

3.6
self-cooled current lead
vapour enthalpy cooled current lead
current lead capably cooled by an evaporated gas generated by heat load from current leads into cryogen

3.7
heat leakage
non-current heat leakage
heat conducted from higher temperature portion into lower temperature portion of the current lead at zero current operation without any Joule heating

3.8
heat load
total heat induced into a cryogenic system through the current leads under current-carrying operation

3.9
rated current heat load
heat load at a rated current operation

4 Principles

The powering of superconducting equipment is made via components that provide the electrical link between the room temperature environment and the cryogenic temperature of the powered equipment. These components are called current leads. Since they operate in a gradient of temperature and they transport current into the cryogenic environment, they are one of the major sources of a heat leakage into the cryostat.

The current leads can be classified into two types:

– normal conducting current leads, made entirely from normal conducting section. These are usually joined at their cold end to a superconducting (SC) bus or link leading to the device being powered;
– high temperature superconducting (HTS) current leads, which incorporate a section of HTS material. A normal conducting section is necessary to conduct the current from room temperature to the warm end of the HTS section. The latter must be maintained at a sufficiently low temperature to ensure that it remains superconducting for the maximum rated current of the lead. The cold end of the HTS section is usually joined to the device by a SC bus.

Depending on the cooling method, the leads can be either non-gas-cooled or gas-cooled. Both types of cooling methods can be used if the lead is subdivided into two, hydraulically separated, sections. If the device being powered uses low temperature superconducting (LTS) material, the link to the lead is usually via LTS cables or wires.

Optimized, self-cooled normal conducting current leads conduct into the helium bath 1,1 W/kA [1][1)] to 1,2 W/kA [2]. This value can be reduced substantially by using HTS material. HTS current

1) Figures in square brackets refer to the Bibliography.

leads have been extensively studied, designed and tested, and are already being integrated into large-scale systems [3] [4].

The design of a current lead is uniquely linked to the system within which it has to operate. The choice of materials, the cooling method, the geometry, the electrical characteristics and the admissible cryogenic consumptions are strongly influenced by boundary conditions imposed by the whole system. System requirements are electrical, cryogenic, and mechanical, and include the following:

– maximum operating current, operation mode, current ramp rate, insulation voltage, circuit time constant, ambient magnetic fields;
– cryogen availability, cryogen inlet/outlet temperature and pressure, admissible heat loads, time duration when the lead shall operate safely in case of failure of cryogen supply;
– the volume available for integration, including mechanical support, vacuum insulation, and connection to the hydraulic and electrical interfaces.

NOTE 1 The heat leakage for self-cooled current leads should make use of 1,2 W/kA in the case of large current capacities.

NOTE 2 Typical current leads based on these principles are shown in Annex B.

5 Characteristic test items

The following clauses describe the qualification tests that should be performed on a current lead at both room and cryogenic temperatures in order to verify its mechanical, electrical and thermal performance. It is assumed that the design of the current lead has been carried out in consideration of general versatility. Before application to an actual system, it is also necessary to do the optimization of the current lead according to the constraints imposed by each system. The characteristic test items shown in Table 1 should enable the user to verify if the current lead meets the specified requirements, and to judge if the test items meet the execution stage of the current lead. It is the responsibility of the user of this standard to select the appropriate tests according to Table 1 considering the boundary conditions of the current leads.

Table 1 – Characteristic test items and test execution stages for current leads

	Characteristic test category	Test items	Characteristic test execution stage		
			R&D[a]	Catalogue[b]	Receive[c]
1	Mechanical characteristics	Structure inspection		Yes	Yes
		Stress/strain effect test	Yes		
2	Thermal properties	Non-current heat leakage test	Yes	Yes	
		Rated current heat load test	Yes	Yes	
3	Electrical characteristics	Rated current-carrying test	Yes	Yes	
		Contact resistance test	Yes		
		High voltage test	Yes	Yes	
		Voltage drop test	Yes	Yes	
4	Hydraulic characteristics	Pressure drop test with rated gas flow	Yes	Yes	
		Leak tightness test	Yes		
5	Safety margin characteristics	Cryogen failure test	Yes	Yes	
		Quench test	Yes		
		Maximum pressure test	Yes	Yes	

NOTE 4 Characteristic test items and methods for the components of HTS section are shown in Annex D.

[a] "R&D" means the test stage for basic research or trial productions of current lead systems.

[b] "Catalogue" means the test stage for performed R&D or mass production of the current leads.

[c] "Receive" means the test stage after installation of the current lead system in the site.

6 Characteristic test methods

The test methods listed here are recommendations. The user may also select other test methods if required by specific applications or boundary conditions.

6.1 Structure inspection

6.1.1 Purpose

This test shall inspect dimensions, applicable materials, structure, structural state and so on as well as the thermal insulation property and leak tightness of the container in the target system.

6.1.2 Methods

The structure inspection test at room temperature shall inspect dimensions, applicable materials, structure, structural state and so on.

The structure inspection test at low temperature shall inspect visually the state of frost forming on the surface of a cryostat filled with cryogen or connected to a refrigerator. As for cryostats with the vacuum thermal insulating layer, it shall be confirmed that there is no malfunction in the layer such as tears and/or collapsing.

6.1.3 Results

Test results shall be collated with the specifications and fully reported.