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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Superconductivity –
Part 21: Superconducting wires – Test methods for practical superconducting wires – General characteristics and guidance

Supraconductivité –
Partie 21: Fils supraconducteurs – Méthodes d'essai pour fils supraconducteurs à usage pratique – Caractéristiques générales et lignes directrices

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COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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SUPERCONDUCTIVITY –

Part 21: Superconducting wires – Test methods for practical superconducting wires – General characteristics and guidance

FOREWORD

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

FDIS	Report on voting
90/353/FDIS	90/354/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 the parts in 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- withdrawn,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.

INTRODUCTION

Superconducting (SC) wires are a central and often enabling technology of many important industrial products. Consensus-based standards for SC wires greatly facilitate the creation of procurement specifications, design and engineering of components, certification of quality, description of operating devices, and generalization of use in industrial technologies.

This part of IEC 61788 is ranked as a first priority for both producers and users of superconducting technology: It provides the measurement methods and test procedures for properties critical to use. Adherence to normative information assists the development of commercial markets and the distribution of products. Standardization in this regard is meant to provide common access to, and unarguable reference information about, characteristics that are most important for superconductor-based technologies.

This part of IEC 61788 includes the measurement principles and measurement techniques together with the relevant terminology and definitions. Specifications of SC wire products take into account the function of the different components of SC wires to meet operational needs, maintain operational (superconducting) conditions, and accommodate mechanical forces and strains. The various forms of SC wire products distributed by manufacturers incorporate these aspects to varying degrees, depending on the superconducting materials used and the intended operating conditions/environment. Design and engineering of devices that use SC wire products take into account the unique properties of SC wires during operation. The general features of practical SC wires are described in IEC TR 61788-20 in terms of simple general characteristics to assist in the specification and use of superconducting wire products. Testing, certification, and quality control apply the relevant standard test methods to SC wires, which are specified in this part of IEC 61788.

SUPERCONDUCTIVITY –

**Part 21: Superconducting wires –
Test methods for practical superconducting wires –
General characteristics and guidance**

1 Scope

This part of IEC 61788 specifies the test methods used for validating the mechanical, electrical, and superconducting properties of practical SC wires. A wire is considered as being practical if it can be procured in sufficiently continuous lengths under ordinary commercial transactions to build devices. Conductors made of multiple wires, such as cables, are not included in the scope of this part of IEC 61788. Extension of the discussions in this part of IEC 61788 beyond practical SC wires is not intended, even though referenced documents include aspects outside of this scope.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts), *International Electrotechnical Vocabulary.* Available from: http://www.electropedia.org

IEC 61788-1, *Superconductivity – Part 1: Critical current measurement – DC critical current of Nb-Ti composite superconductors*

IEC 61788-2, *Superconductivity – Part 2: Critical current measurement – DC critical current of Nb_3Sn composite superconductors*

IEC 61788-3, *Superconductivity – Part 3: Critical current measurement – DC critical current of Ag- and/or Ag alloy-sheathed Bi-2212 and Bi-2223 oxide superconductors*

IEC 61788-4, *Superconductivity – Part 4: Residual resistance ratio measurement – Residual resistance ratio of Nb-Ti composite superconductors*

IEC 61788-5, *Superconductivity – Part 5: Matrix to superconductor volume ratio measurement – Copper to superconductor volume ratio of Cu/Nb-Ti composite superconducting wires*

IEC 61788-6, *Superconductivity – Part 6: Mechanical properties measurement – Room temperature tensile test of Cu/Nb-Ti composite superconductors*

IEC 61788-8, *Superconductivity – Part 8: AC loss measurements – Total AC loss measurement of round superconducting wires exposed to a transverse alternating magnetic field at liquid helium temperature by a pickup coil method*

IEC 61788-10, *Superconductivity – Part 10: Critical temperature measurement – Critical temperature of composite superconductors by a resistance method*

IEC 61788-11, *Superconductivity – Part 11: Residual resistance ratio measurement – Residual resistance ratio of Nb_3Sn composite superconductors*

IEC 61788-12, *Superconductivity – Part 12: Matrix to superconductor volume ratio measurement – Copper to non-copper volume ratio of* Nb_3Sn *composite superconducting wires*

IEC 61788-13, *Superconductivity – Part 13: AC loss measurements – Magnetometer methods for hysteresis loss in superconducting multifilamentary composites*

IEC 61788-18, *Superconductivity – Part 18: Mechanical properties measurement – Room temperature tensile test of Ag- and/or Ag alloy-sheathed Bi-2223 and Bi-2212 composite superconductors*

IEC 61788-19, *Superconductivity – Part 19: Mechanical properties measurement – Room temperature tensile test of reacted* Nb_3Sn *composite superconductors*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-815 apply.

4 Characteristic attributes of practical SC wires

The primary purpose of electrical wires is to carry electrical current. Practical SC wires have the same intended purpose as common electrical wires, with the special ability to carry hundreds or thousands of times more current than a common electrical wire of the same dimension. Standard test methods discussed in this part of IEC 61788 address the determination of current-carrying capacity, called the critical current of practical SC wires. Several by-products of the special circumstances of practical SC wires also necessitate additional standards discussed in this part of IEC 61788 with respect to mechanical and thermal properties as well as properties in magnetic fields. The details are described in Annex A.

5 Categories of properties

The properties necessary for the specification are categorized as follows:

a) properties referring to the operation of SC wires, e.g. incurred during the initial cool-down to operating temperature, standard continuous operation, and under fault conditions;

b) properties related to implementation and engineering, e.g. incurred during the fabrication and installation of a device.

With respect to the properties belonging to two categories, their principal test methods have been established as parts of IEC 61788 series indicated in Clause 6.

6 Properties governed by IEC standards

6.1 General

Several attributes are governed by parts of the IEC 61788 series. Test methods for these attributes shall be used to settle disputes. When a new test method is established as a part of IEC 61788 series, it will be included in Clause 6.

6.2 Properties referring to the operation of SC wires

For the purpose of consultation, current parts of the IEC 61788 series related to specific properties shall be used to settle disputes. They are categorized in groups as follows:

a) Critical temperature:

– Critical temperature measurement – Critical temperature of composite superconductors by a resistance method (IEC 61788-10).

b) Critical current:

– Critical current measurement – DC critical current of Nb-Ti composite superconductors (IEC 61788-1);

– Critical current measurement – DC critical current of Nb_3Sn composite superconductors (IEC 61788-2);

– Critical current measurement – DC critical current of Ag- and/or Ag alloy-sheathed Bi-2212 and Bi-2223 oxide superconductors (IEC 61788-3).

c) AC loss:

– AC loss measurements – Total AC loss measurement of round superconducting wires exposed to a transverse alternating magnetic field at liquid helium temperature by a pickup coil method (IEC 61788-8);

– Magnetometer methods for hysteresis loss in superconducting multifilamentary composites (IEC 61788-13).

6.3 Properties related to implementation and engineering

For the purpose of consultation, current parts of the IEC 61788 series related to implementation and engineering shall be used to settle disputes. They are categorized in groups as follows.

a) Matrix to superconductor volume ratio:

– Matrix to superconductor volume ratio measurement – Copper to superconductor volume ratio of Cu/Nb-Ti composite superconducting wires (IEC 61788-5);

– Matrix to superconductor volume ratio measurement – Copper to non-copper volume ratio of Nb_3Sn composite superconducting wires (IEC 61788-12).

b) Residual resistance ratio:

– Residual resistance ratio measurement – Residual resistance ratio of Nb-Ti composite superconductors (IEC 61788-4);

– Residual resistance ratio measurement – Residual resistance ratio of Nb_3Sn composite superconductors (IEC 61788-11).

c) Mechanical properties:

– Mechanical properties measurement – Room temperature tensile test of Cu/Nb-Ti composite superconductors (IEC 61788-6);

– Mechanical properties measurement – Room temperature tensile test of Ag- and/or Ag alloy-sheathed Bi-2223 and Bi-2212 composite superconductors (IEC 61788-18);

– Mechanical properties measurement – Room temperature tensile test of reacted Nb_3Sn composite superconductors (IEC 61788-19).

Annex A
(informative)

Characteristic attributes of practical SC wires

A.1 General

Procurement of practical SC wires generally requires the specification of performance for one or many properties. The manufacturer, supplier, and customer should agree on which properties are important for their application, and then determine specifications of performance for those properties. Standards described in the preceding clauses are intended for the measurement of actual performance, such as for certification or assurance to meet the specification. Annex A describes briefly the various properties that could be considered in commercial transactions.

A.2 Critical temperature

When a SC material is cooled down, it transforms from a normal to superconducting state at a critical temperature (T_c). A large supercurrent can be carried with small Joule loss, because the DC electrical resistance is almost zero in the SC state. The operation of the SC wire in real application should be carried out at temperatures lower than T_c with sufficient enough temperature margin, because the instability increases rapidly as the temperature becomes close to T_c.

In standard operation, practical SC wires are cooled below their critical temperature, and therefore a metal to conduct heat to a coolant is incorporated into the wire architecture. Standards to evaluate the purity and conductivity of this metal are described. Also, standards to evaluate the temperature and magnetic field at which the practical SC wire is in the superconducting state are described.

There are also certain types of application, such as fault current limiters, that make use of the transition of the SC wire from the superconducting state to the normal conducting state. For such applications, the SC wire will experience temperatures above T_c and the electrical and thermal stabilization of the wire is considered individually with regards to specific application requirements. Major requirements are to limit temperature rise, to achieve thermal recovery within a specific duration and to limit fault currents to a maximum level.

A.3 Critical magnetic and irreversibility fields

When an external magnetic field higher than the lower critical field is applied to a practical superconductor, a so-called mixed state appears where quantized magnetic flux is introduced into the SC material. In this mixed state, large supercurrent can flow steadily in the superconductor without the generation of voltage. The ability of the SC material to carry large supercurrents without dissipation in the mixed state makes it possible to design a SC magnet operating at high magnetic field. However when the external magnetic field exceeds the irreversibility value, the supercurrent is accompanied by a voltage. The mixed state would be destroyed once the external field is above the upper critical magnetic field.

A common use of practical SC wires is the winding of electro-magnets. Under such conditions, the SC wire is placed in a high magnetic field, which can induce properties not found for common electrical wires. Standards to evaluate the different behaviour, such as the magnetization of a practical SC wire, are described. In addition, certain field limits apply to the superconducting state.

A.4 Critical current and *n*-value

Theoretically the critical current is defined as the maximum direct current that can be regarded as flowing without resistance (IEC 60050-815). In practice however, the critical current is determined based on measurement sensitivities of the devices used to characterize dissipation of the SC wire, and thus, the practical definition is determined according to a criterion based on finite value of resistivity or electric field (IEC 61788-1, IEC 61788-2 and IEC 61788-3). High performance practical SC wires developed recently can transport current at least a factor of 10^2 to 10^3 times higher than common copper electrical wires of the same dimension. The critical current is largely dependent on temperature and magnetic field, and is dependent on mechanical strain. Electric voltage appears rapidly in proportion to $(I/I_c)^n$, when current I approaches and exceeds the critical current. The exponential index is called "*n*-value", which indicates the sharpness of transition to the magnetic flux flow state.

A.5 Stability

When the SC state breaks down, a local part of the superconductor carrying a large supercurrent becomes normal and generates potential instability due to Joule heat. The practical SC wire is designed to avoid the expansion of such a current instability. In the case of Nb_3Sn composite superconducting wire, for instance, the high conductivity copper surrounds the core including Nb_3Sn filaments.

Practical SC wires are designed to conduct heat to an external coolant, often through a high conductivity metal stabilizer such as copper, silver, or aluminum that surrounds the superconducting material on the inside. Characterization of the heat-carrying capacity of the stabilizer is often performed via measurement of the residual resistivity ratio, (RRR). The transformation to the superconducting state at low temperatures short-circuits the electrical path through the stabilizer, which makes such measurements more complicated than for common wires.

For SC wires used for such applications as fault current limiters, in which the SC wire transitions from the superconducting state to the normal conducting state and temperatures well-above T_c are experienced, the stability requirements become different. The thermal and electrical stabilization of the practical SC wire are designed to limit temperature rise, achieve thermal recovery within a specified duration and to limit fault currents to a maximum level. For such applications, heat capacity and electrical resistance of the stabilization components at temperatures above T_c are important parameters.

A.6 AC loss

When an AC magnetic field or an AC current is applied to SC wires, heat generation takes place due to hysteresis, coupling between superconducting elements, and eddy current losses from complementary metallic components. In some important applications, a large heat generation is expected and the SC wires used are specifically designed to prevent the break-down of the SC state from the heat generated. In the case of Nb-Ti composite superconducting wire, for instance, the Nb-Ti filaments are twisted and the Cu-Ni alloy element is inserted in the copper matrix.

Practical SC wires respond to changes of magnetic field in ways that are different from the response of common wires. Some behaviour produces heat, which can affect the cryogenic conditions of operation. Standards are described to evaluate the lossy effects specific to practical SC wires.

A.7 Strain-dependent superconducting properties

Due to their complicated composite structure, the properties and architecture of the component materials affect the internal stress/strain in the SC component, which significantly influences the