IEC 61788-27

Edition 1.0 2025-02

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Superconductivity –
Part 27: Twist pitch measurement of practical superconducting wires – Twist pitch measurement of Nb-Ti/Cu and Nb-Sn/Cu composite superconductors

Supraconductivité –
Partie 27: Mesurage du pas de torsade de fils supraconducteurs pratiques – Mesurage du pas de torsade des composites supraconducteurs Nb-Ti/Cu et Nb-Sn/Cu

IEC 61788-27:2025-02(en-fr)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

IEC 61788-27

Edition 1.0 2025-02

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Superconductivity –
Part 27: Twist pitch measurement of practical superconducting wires – Twist pitch measurement of Nb-Ti/Cu and Nb-Sn/Cu composite superconductors

Supraconductivité –
Partie 27: Mesurage du pas de torsade de fils supraconducteurs pratiques – Mesurage du pas de torsade des composites supraconducteurs Nb-Ti/Cu et Nb-Sn/Cu

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 29.050 ISBN 978-2-8327-0133-1

Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SUPERCONDUCTIVITY –

Part 27: Twist pitch measurement of practical superconducting wires – Twist pitch measurement of Nb-Ti/Cu and Nb-Sn/Cu composite superconductors

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users shall ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 61788-27 has been prepared by IEC technical committee 90: Superconductivity. It is an International Standard.

The text of this International Standard is based on the following documents:

Draft	Report on voting
90/532/FDIS	90/540/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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 document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

INTRODUCTION

Twisting of multi-filamentary superconductors is an important step in the development of wires with AC losses at an acceptable level for AC applications. The necessary twist pitch depends on wire architecture, critical current density, matrix material, and external factors such as temperature, frequency and applied magnetic field.

Therefore, twist pitch is a very important parameter in the design and application of composite superconducting wires, which is often inspected in the last stage of fabrication. Due to the different architectures of different composite superconductors, appropriate test methods should be adopted for specific architectures.

This document specifies the untwisting method for measuring the twist pitch of Nb-Ti/Cu and Nb-Sn/Cu composite superconductors [1][1]. As supplementary methods, the direct measurement method and the image processing method [1] are specified in Annex A and Annex B, respectively.

[1] Numbers in square brackets refer to the Bibliography.

SUPERCONDUCTIVITY –

Part 27: Twist pitch measurement of practical superconducting wires – Twist pitch measurement of Nb-Ti/Cu and Nb-Sn/Cu composite superconductors

1 Scope

This part of IEC 61788 specifies a test method for the twist pitch measurement of Nb-Ti/Cu and Nb-Sn/Cu composite superconductors by an untwisting method.

The test method is applicable to Nb-Ti/Cu and Nb-Sn/Cu composite superconducting wires with monolithic structures, which have either a round cross section with a diameter ranging from 0,2 mm to 2 mm or a rectangular cross section that is equivalent in area to the round cross-sectional wires. These wires possess a filament diameter ranging from 6 µm to 200 µm, a twist pitch between 5 mm and 50 mm, and a matrix of copper or copper alloy. This document uses nitric acid to remove the matrix (copper or copper alloy), so the surface of the composite superconducting wire can be plated with a material that is dissolvable by nitric acid.

Though uncertainty can increase, the method can apply to Nb-Ti/Cu or Nb-Sn/Cu composite superconducting wires when the parameters of cross-sectional area, filament diameter and twist pitch are out of the limit.

The test method specified in this document is expected to apply to other types of composite superconducting wires after some appropriate modifications.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
twist
turns made by a filament around a central wire axis

[SOURCE: IEC 60050-815:2015 [2], 815-13-46, modified – In the definition, "or strand" has been deleted and "conductor" has been replaced with "central wire".]

3.2
twist direction
direction of a filament in twist

Note 1 to entry: There are two types of twist direction: Z-twist (sometimes referred to as right-hand twist) when the filament or strand is twisted in a clockwise direction and S-twist (sometimes referred to as left-hand twist) when the filament or strand is twisted in an anticlockwise direction.

3.3
twist pitch
L_p
axial length in which a filament firstly returns to its original relative position in a twisted superconducting wire

[SOURCE: IEC 60050-815:2015 [2], 815-13-47, modified – The preferred term "twist pitch length" has been deleted. In the definition, "or strand" has been deleted and "conductor" has been replaced with "superconducting wire".]

3.4
twist angle
untwist angle
θ
angle at which all filaments of a twisted superconducting wire return to parallel original axial positions during the untwisting process

4 Principle

Low temperature superconducting wire is usually composed of tens to even thousands of superconducting filaments embedded in copper and copper alloy matrix. After the superconducting wire is twisted, the inner filaments are also regularly twisted with a specific twist pitch. This document specifies an untwisting method to measure the twist pitch (see Figure 1).

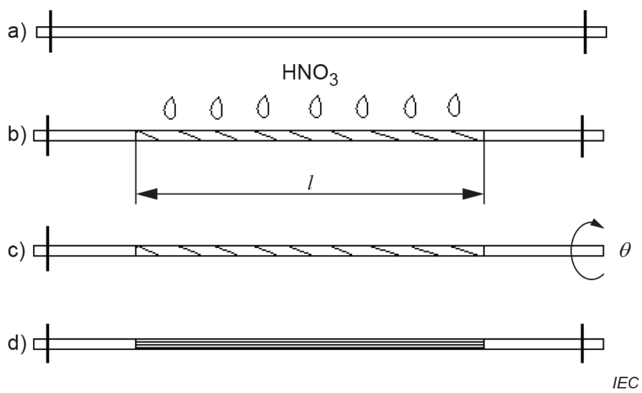

Figure 1 – Principle demonstration

The untwisting method can be briefly described as follows.

a) Fix the two ends of the specimen (Figure 1a).
b) Remove the copper or copper alloy matrix in the middle section of the specimen with HNO_3 solution (Figure 1b).
c) Measure the length of the dissolved zone (denoted as l, explanation see 8.4).
d) Rotate one end of the wire to untwist it until the filaments in the dissolved zone are parallel (Figure 1c and Figure 1d). Record the rotated angle (denoted as θ).

e) Calculate the twist pitch L_p using l and θ (see Formulae (1) and (2)).

The other two normative methods, the direct measurement method and the image processing method, are specified in Annex A and Annex B, which are equivalent alternatives.

5 Reagents and auxiliary materials

The following reagents shall be prepared for specimen preparation:

– detergent and degreaser;
– anhydrous ethanol;
– nitric acid solution (40 % to 65 % mass percentage concentration is recommended).
  Rubber gloves and acid-resistant tweezers shall be used when handling acid solution.

The following auxiliary materials and tools shall be prepared for specimen preparation:

– 300 to 800 mesh fine sandpaper (apply to Nb-Sn/Cu specimens only).

6 Apparatus and tools

The apparatus and tools required for measurement shall include the following:

– an auxiliary tool for twist pitch measurement, which has an angle scale with an accuracy of 5° or better (an example is given in Annex C);
– fume hood;
– calliper (accuracy 0,02 mm or better);
– oven or dryer.

7 Specimen preparation

7.1 Requirements

The untwisting method shall be used for twist pitches in the range of 5 mm to 50 mm to ensure adequate accuracy for the measurement. The specimen length shall be longer than six times of the nominal twist pitch.

The specimen shall be free from torsion and bending.

7.2 Cleaning

Detergent and degreaser shall be used to remove oil stains and other contamination from the specimen. Then, the specimen shall be rinsed repeatedly with running water, and finally dehydrated by anhydrous ethanol.

7.3 Drying

After cleaning, the specimen shall be dried completely in an appropriate manner. For example, drying with hot air or placed into an oven (60 °C to 70 °C).

7.4 Removing matrix copper and sanding barrier (apply to Nb-Sn/Cu specimen of external stabilizer type only)

Some Nb-Sn/Cu wires have a Nb or Ta external diffusion barrier to inhibit diffusion reaction between Cu-Sn matrix and external copper stabilizer, and the barrier is insoluble in nitric acid. When the external copper stabilizer is dissolved, this barrier prevents the inner copper from being corroded by nitric acid, therefore the barrier shall be removed. The following steps are recommended when removing the barrier; these steps are not applied to distributed barrier wires.

a) Removing matrix copper: Immerse the Nb-Sn/Cu specimen in nitric acid solution and leave the container in a fume hood for about 15 minutes until the copper sheath of the specimen is completely dissolved. Take the specimen out by acid-resistant tweezers, rinse it with running water, and then dehydrate it with anhydrous ethanol, and dry it.

   For safety, wear long sleeves, trousers, and rubber gloves to prevent nitric acid from splashing on the skin.

b) Inspecting barrier surface for barrier seam: If the barrier has a seam, inspect the surface of the barrier which will follow the filament position underneath. If a seam is clearly visible, the specimen needs no further preparation.

c) Sanding barrier: Take a fine sandpaper, and evenly sand the measuring section until the internal coppery red is completely exposed.

   Use a fume hood during sanding.

d) Cleaning and drying: Clean and dry the specimen in accordance with 7.2 and 7.3, respectively.

8 Measurement procedure

8.1 Specimen fixing

If necessary, for Nb-Sn/Cu specimens with external diffusion barrier, the barrier shall be removed in advance in accordance with 7.4. Both ends of the specimen shall be clamped or pressed tightly to the auxiliary tool to straighten the specimen. During the fixing process, distortion, bending, or any other actions that will affect the measurement results are not allowed.

8.2 Specimen dissolution

Immerse the middle part of the specimen, approximately two thirds of the total length, in nitric acid solution and hold for about 30 minutes. This can be achieved by pushing the slider in the auxiliary tool toward the centre, and thus bending the specimen at the same time. Details are given in Annex C.

Take the dissolved part out and observe inner filaments. If there is still residual copper or filament bonding, or the dissolved zone boundary is not clear, immerse the part into nitric acid solution again. Ensure that the position of the specimen relative to the nitric acid surface does not change so that boundaries of the dissolution zone are as clear as possible.

Use personal protective equipment and a fume hood while handling the specimen.

8.3 Cleaning and drying

When all the inner filaments are fully dispersed with no residual copper, take the dissolved part out, with the whole specimen still fixed on the auxiliary tool. Clean and dry the specimen in accordance with 7.2 and 7.3, respectively.

8.4 Measurement

Restore the specimen in the auxiliary tool to the initial state, horizontal without bending, and observe the twist direction. While fixing the axial position of the specimen, rotate one end of it in the opposite direction to untwist it. Meanwhile, observe the filaments or barrier seam carefully, and stop rotating when all filaments or barrier seam are nearly parallel to the wire axis.

Insert two pieces of thin plate, such as copper foils, with approximately 0,5 mm thickness and 10 mm to 30 mm width. Two pieces of plate are overlapped, without any filament between them. They are both applied to pick up several filaments. One of them is kept at the start of the dissolved zone, and the other slides towards the end of the zone. Tune the angle at the same time until the picked filaments are completely untwisted, that is, those filaments are now parallel to the wire axis of the specimen. Alternatively, if there is a visible seam on the barrier, use the apparatus to untwist the wire until the seam runs parallel to the wire axis.

Record the total rotation angle, i.e. twist angle θ. It is recommended to repeat the previous step several times to improve the measurement accuracy.

Measure the length of the picked filaments by a calliper, using the copper foils marking the boundaries. It is recommended to carry out multiple measurements to improve the measurement accuracy. It is worth noting that, by twist pitch definition, l is the length in twist state. However, since the boundary of the dissolved zone is difficult to identify, this compromise is justified. On one hand, an appropriate auxiliary tool can be designed to fix the position of both ends of the specimen, as seen in Annex C, so that the distance of the dissolved part remains unchanged. On the other hand, the untwisting process cannot guarantee that all filaments are completely parallel. Thus, only the length or distance of the picked filaments is measured. The introduced uncertainty is considered in the uncertainty evaluation (Annex D).

For another dissolution method, the specimen is dissolved, cleaned and dried in advance, and then fixed to the tool for measurement. In this case, the dissolved specimen shall not be twisted before and during fixing.

9 Calculation of results

The twist pitch shall be calculated and rounded to one decimal using Formulae (1) and (2):

$$L_\mathrm{p} = \frac{l}{n} \tag{1}$$

$$n = \frac{\theta}{360} \tag{2}$$

where

L_p is the twist pitch (mm);

l is the length of the dissolved zone (mm);

n is the number of turns;

θ is the untwist angle (°).

10 Uncertainty of measurement

The twist pitch is obtained by measuring the dissolved zone length l and the untwist angle θ. The target relative expanded standard uncertainty (RSU) of measurement shall not exceed 2 % (k = 2). Details of the uncertainty evaluation are described in Clause D.1.