

# INTERNATIONAL STANDARD

# NORME INTERNATIONALE



**Superconductivity –** **STANDARD PREVIEW**  
**Part 6: Mechanical properties measurement – Room temperature tensile test**  
**of Cu/Nb-Ti composite superconductors**  
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**Supraconductivité –** **IEC 61788-6:2011**  
**Partie 6: Mesure des propriétés mécaniques – Essai de traction à température**  
**ambiante des supraconducteurs composites de Cu/Nb-Ti**



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## SUPERCONDUCTIVITY –

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

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International Standard IEC 61788-6 has been prepared by IEC technical committee 90: Superconductivity.

This third edition cancels and replaces the second edition published in 2008. It constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- specific example of uncertainty estimation related to mechanical tests was supplemented as Annex C.

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

FDIS	Report on voting
90/267/FDIS	90/278/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.

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## INTRODUCTION

The Cu/Nb-Ti superconductive composite wires currently in use are multifilamentary composite material with a matrix that functions as a stabilizer and supporter, in which ultrafine superconductor filaments are embedded. A Nb-40~55 mass % Ti alloy is used as the superconductive material, while oxygen-free copper and aluminium of high purity are employed as the matrix material. Commercial composite superconductors have a high current density and a small cross-sectional area. The major application of the composite superconductors is to build superconducting magnets. While the magnet is being manufactured, complicated stresses are applied to its windings and, while it is being energized, a large electromagnetic force is applied to the superconducting wires because of its high current density. It is therefore indispensable to determine the mechanical properties of the superconductive wires, of which the windings are made.

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## SUPERCONDUCTIVITY –

### Part 6: Mechanical properties measurement – Room temperature tensile test of Cu/Nb-Ti composite superconductors

#### 1 Scope

This part of IEC 61788 covers a test method detailing the tensile test procedures to be carried out on Cu/Nb-Ti superconductive composite wires at room temperature.

This test is used to measure modulus of elasticity, 0,2 % proof strength of the composite due to yielding of the copper component, and tensile strength.

The value for percentage elongation after fracture and the second type of 0,2 % proof strength due to yielding of the Nb-Ti component serves only as a reference (see Clauses A.1 and A.2).

The sample covered by this test procedure has a round or rectangular cross-section with an area of 0,15 mm<sup>2</sup> to 2 mm<sup>2</sup> and a copper to superconductor volume ratio of 1,0 to 8,0 and without the insulating coating.

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#### 2 Normative references

[IEC 61788-6:2011](https://standards.iteh.ai/catalog/standards/sis/61788-6-2011)

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, *International Electrotechnical Vocabulary – Part 815: Superconductivity*

ISO 376, *Metallic materials – Calibration of force-proving instruments used for the verification of uniaxial testing machines*

ISO 6892-1, *Metallic materials – Tensile testing – Part 1: Method of test at room temperature*

ISO 7500-1, *Metallic materials – Verification of static uniaxial testing machines – Part 1: Tension/compression testing machines – Verification and calibration of the force-measuring system*

ISO 9513, *Metallic materials – Calibration of extensometers used in uniaxial testing*

#### 3 Terms and definitions

For the purposes of this document, the definitions given in IEC 60050-815 and ISO 6892-1, as well as the following, apply.

##### 3.1

##### **tensile stress**

tensile force divided by the original cross-sectional area at any moment during the test

### 3.2 tensile strength

$R_m$   
tensile stress corresponding to the maximum testing force

NOTE The symbol  $\sigma_{UTS}$  is commonly used instead of  $R_m$ .

### 3.3 extensometer gauge length

length of the parallel portion of the test piece used for the measurement of elongation by means of an extensometer

### 3.4 distance between grips

$L_g$   
length between grips that hold a test specimen in position before the test is started

### 3.5 0,2 % proof strength

$R_{p0,2}$  (see Figure 1)  
stress value where the copper component yields by 0,2 %

NOTE 1 The designated stress,  $R_{p0,2A}$  or  $R_{p0,2B}$  corresponds to point A or B in Figure 1, respectively. This strength is regarded as a representative 0,2 % proof strength of the composite. The second type of 0,2 % proof strength is defined as a 0,2 % proof strength of the composite where the Nb-Ti component yields by 0,2 %, the value of which corresponds to the point C in Figure 1 as described complementarily in Annex A (see Clause A.2).

NOTE 2 The symbol  $\sigma_{0,2}$  is commonly used instead of  $R_{p0,2}$ .

### 3.6 modulus of elasticity

$E$   
gradient of the straight portion of the stress-strain curve in the elastic deformation region

## 4 Principle

The test consists of straining a test piece by tensile force, generally to fracture, for the purpose of determining the mechanical properties defined in Clause 3.

## 5 Apparatus

### 5.1 Conformity

The test machine and the extensometer shall conform to ISO 7500-1 and ISO 9513, respectively. The calibration shall obey ISO 376. The special requirements of this standard are presented here.

### 5.2 Testing machine

A tensile machine control system that provides a constant cross-head speed shall be used. Grips shall have a structure and strength appropriate for the test specimen and shall be constructed to provide an effective connection with the tensile machine. The faces of the grips shall be filed or knurled, or otherwise roughened, so that the test specimen will not slip on them during testing. Gripping may be a screw type, or pneumatically or hydraulically actuated.

### 5.3 Extensometer

The weight of the extensometer shall be 30 g or less, so as not to affect the mechanical properties of the superconductive wire. Care shall also be taken to prevent bending moments from being applied to the test specimen (see Clause A.3).

## 6 Specimen preparation

### 6.1 Straightening the specimen

When a test specimen sampled from a bobbin needs to be straightened, a method shall be used that affects the material as little as possible.

### 6.2 Length of specimen

The total length of the test specimen shall be the inward distance between grips plus both grip lengths. The inward distance between the grips shall be 60 mm or more, as requested for the installation of the extensometer.

### 6.3 Removing insulation

If the test specimen surface is coated with an insulating material, that coating shall be removed. Either a chemical or mechanical method shall be used, with care taken not to damage the specimen surface (see Clause A.4).

### 6.4 Determination of cross-sectional area ( $S_0$ )

A micrometer or other dimension-measuring apparatus shall be used to obtain the cross-sectional area of the specimen after the insulation coating has been removed. The cross-sectional area of a round wire shall be calculated using the arithmetic mean of the two orthogonal diameters. The cross-sectional area of a rectangular wire shall be obtained from the product of its thickness and width. Corrections to be made for the corners of the cross-sectional area shall be determined through consultation among the parties concerned (see Clause A.5).

## 7 Testing conditions

### 7.1 Specimen gripping

The test specimen shall be mounted on the grips of the tensile machine. At this time, the test specimen and tensile loading axis must be on a single straight line. Sand paper may be inserted as a cushioning material to prevent the gripped surfaces of the specimen from slipping and fracturing (see Clause A.6).

### 7.2 Pre-loading and setting of extensometer

If there is any slack in the specimen when it is mounted, a force not greater than one-tenth of the 0,2 % proof strength of the composite shall be applied to take up the slack before the extensometer is mounted. When mounting the extensometer, care shall be taken to prevent the test specimen from being deformed. The extensometer shall be mounted at the centre between the grips, aligning the measurement direction with the specimen axis direction. After installation, loading shall be zeroed.

### 7.3 Testing speed

The strain rate shall be  $10^{-4}/s$  to  $10^{-3}/s$  during the test using the extensometer. After removing the extensometer, the strain rate may be increased to a maximum of  $10^{-3}/s$ .

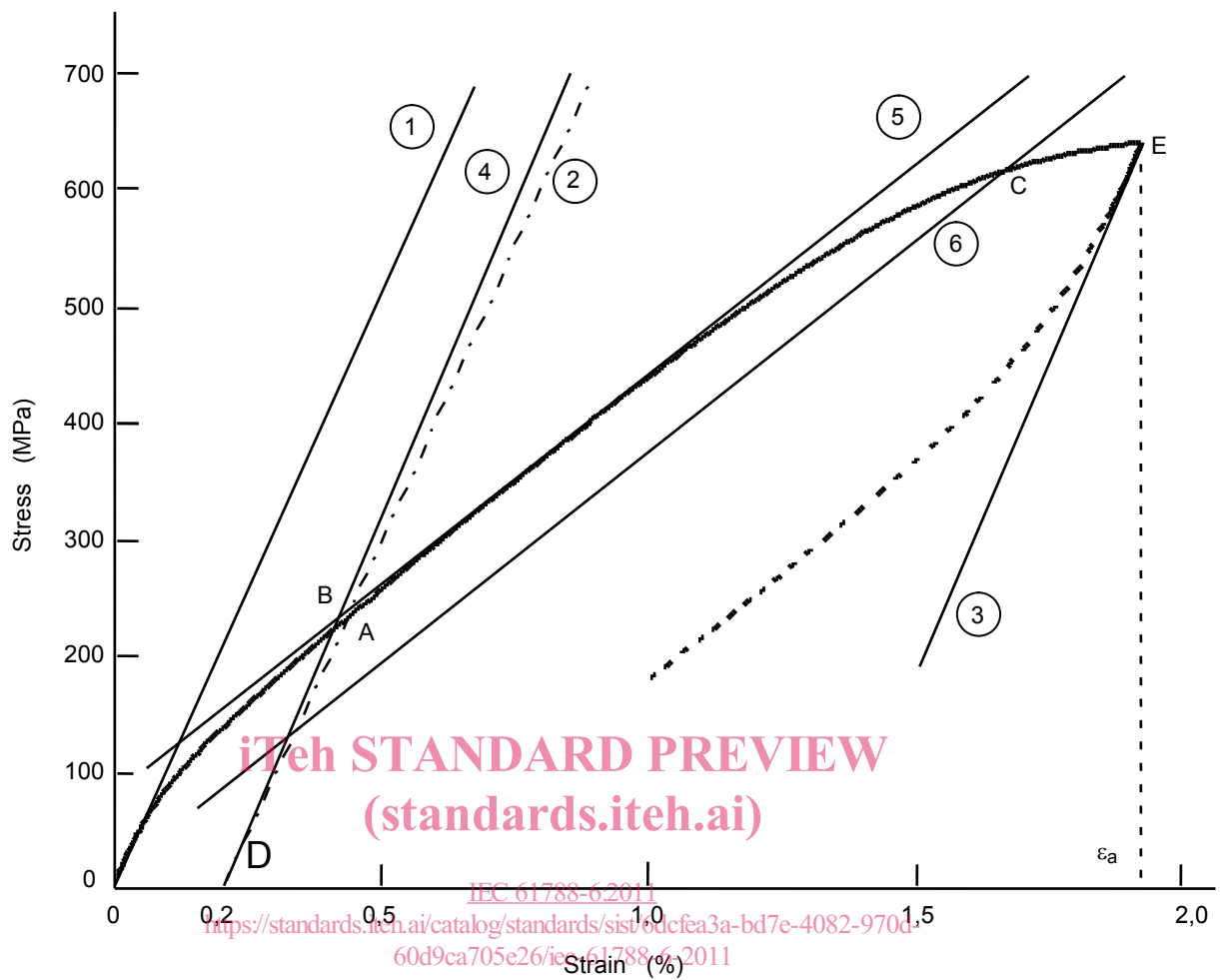
#### 7.4 Test

The tensile machine shall be started after the cross-head speed has been set to the specified level. The signals from the extensometer and load cell shall be plotted on the abscissa and ordinate, respectively, as shown in Figure 1. When the total strain has reached approximately 2 %, reduce the force by approximately 10 % and then remove the extensometer. The step of removing the extensometer can be omitted in the case where the extensometer is robust enough not to be damaged by the total strain and the fracture shock of this test. At this time, care shall be taken to prevent unnecessary force from being applied to the test specimen. Then, increase loading again to the previous level and continue testing until the test specimen fractures. Measurement shall be made again if a slip or fracture occurs on the gripped surfaces of the test specimen.

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**Key**

- ① Initial loading line
- ② Line shifted by an offset of 0,2% parallel to the initial loading line
- ③ Unloading line
- ④ Line shifted by an offset of 0,2% parallel to the unloading line
- ⑤ Second linear part of loading line
- ⑥ Line shifted by an offset of 0,2% parallel to the second linear loading line

NOTE 1 When the total strain has reached ~2 % (point E), the load is reduced by 10 % and the extensometer is removed, if necessary. Then, the load is increased again.

NOTE 2 The slope of the initial loading line is usually smaller than that of the unloading line. Then, two lines can be drawn from the 0,2 % offset point on the abscissa to obtain 0,2 % proof strength of the composite due to yielding of the copper component. Point A is obtained from the initial loading line, and Point B is obtained from the unloading line. Point C is the second type of 0,2 % proof strength of the composite where the Nb-Ti component yields.

**Figure 1 – Stress-strain curve and definition of modulus of elasticity and 0,2 % proof strengths**

## 8 Calculation of results

### 8.1 Tensile strength ( $R_m$ )

Tensile strength  $R_m$  shall be the maximum force divided by the original cross-sectional area of the wire before loading.

### 8.2 0,2 % proof strength ( $R_{p0,2A}$ and $R_{p0,2B}$ )

The 0,2 % proof strength of the composite due to yielding of the copper component is determined in two ways from the loading and unloading stress-strain curves as shown in Figure 1. The 0,2 % proof strength under loading  $R_{p0,2A}$  shall be determined as follows: the initial linear portion under loading of the stress-strain curve is moved 0,2 % in the strain axis (0,2 % offset line under loading) and the point A at which this linear line intersects the stress-strain curve shall be defined as the 0,2 % proof strength under loading. The 0,2 % proof strength of the composite under unloading  $R_{p0,2B}$  shall be determined as follows: the linear portion under unloading is to be moved parallel to the 0,2 % offset strain point. The intersection of this line with the stress-strain curve determines the point B that shall be defined as the 0,2 % proof strength. This measurement shall be discarded if the 0,2 % proof strength of the composite is less than three times the pre-load specified in 7.2.

Each 0,2 % proof strength shall be calculated using formula (1) given below:

$$R_{p0,2i} = F_i / S_0 \quad (1)$$

where

$R_{p0,2i}$  is the 0,2 % proof strength (MPa) at each point;

$F_i$  is the force (N) at each point;

$S_0$  is the original cross-sectional area (in square millimetres) of the test specimen;

Further,  $i = A$  and  $B$ .

### 8.3 Modulus of elasticity ( $E_o$ and $E_a$ )

Modulus of elasticity shall be calculated using the following formula and the straight portion, either of the initial loading curve or of the unloading one.

$$E = \Delta F (1 + \varepsilon_a) / (S_0 \Delta \varepsilon) \quad (2)$$

where

$E$  is the modulus of elasticity (MPa);

$\Delta F$  is the increments (N) of the corresponding force;

$\Delta \varepsilon$  is the increment of strain corresponding to  $\Delta F$ ;

$\varepsilon_a$  is the strain just after unloading as shown in Figure 1.

$E$  is designated as  $E_o$  when using the initial loading curve ( $\varepsilon_a = 0$ ), and as  $E_a$  when using the unloading curve ( $\varepsilon_a \neq 0$ ).

## 9 Uncertainty

Unless otherwise specified, measurements shall be carried in a temperature range between 280 K and 310 K. A force measuring cell with a combined standard uncertainty not greater than 0,5 % shall be used. An extensometer with a combined standard uncertainty not greater than 0,5 % shall be used. The dimension-measuring apparatus shall have a combined standard uncertainty not greater than 0,1 %. The target combined standard uncertainties are defined by root square sum (RSS) procedure, which is given in Annex B.

There are no reliable experimental data with respect to uncertainties on moduli of elasticity and 0,2 % proof strengths as mentioned in Clause A.7. As described in Annex C, on the other hand, their uncertainties could be evaluated from the experimental conditions, of which parts are indicated above like uncertainty of force measuring cell. Consequently the relative expanded uncertainties ( $k=2$ ) for the modulus of elasticity,  $E_o$ , and the 0,2 % proof strength,  $R_{p0,2A}$ , are expected to be 2,0 % ( $N=1$ ) and 0,78 % ( $N=1$ ), respectively, where  $N$  indicates the time of repeated tests.

NOTE Uncertainties reported in the present text, if used for the purpose of practical assessment, have to be taken under the specific considerations with detailed caution as indicated in Annex B.

## 10 Test report

### 10.1 Specimen

- a) Name of the manufacturer of the specimen
- b) Classification and/or symbol
- c) Lot number

The following information shall be reported as necessary.

- d) Raw materials and their chemical composition
  - e) Cross-sectional shape and dimension of the wire
  - f) Filament diameter
  - g) Number of filaments
  - h) Twist pitch of filaments
  - i) Copper to superconductor ratio
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### 10.2 Results

- a) Tensile strength ( $R_m$ )
- b) 0,2 % proof strengths ( $R_{p0,2A}$  and  $R_{p0,2B}$ )
- c) Modulus of elasticity ( $E_o$  and  $E_a$  with  $\varepsilon_a$ )

The following information shall be reported as necessary.

- d) Second type of 0,2 % proof strength ( $R_{p0,2C}$ )
- e) Percentage elongation after fracture ( $A$ )

### 10.3 Test conditions

- a) Cross-head speed
- b) Distance between grips
- c) Temperature

The following information shall be reported as necessary.

- d) Manufacturer and model of testing machine
- e) Manufacturer and model of extensometer
- f) Gripping method