IEC

# IEC 61788-19

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# INTERNATIONAL STANDARD

# NORME INTERNATIONALE

colour inside

## Superconductivity – Part 19: Mechanical properties measurement – Room temperature tensile test of reacted $Nb_3Sn$ composite superconductors

## Supraconductivité – Partie 19: Mesure des propriétés mécaniques – Essai de traction à température ambiante des supraconducteurs composites de $Nb_3Sn$ mis en réaction

IEC 61788-19:2013

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# SUPERCONDUCTIVITY –

## Part 19: Mechanical properties measurement – Room temperature tensile test of reacted $Nb_3Sn$ composite superconductors

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International Standard IEC 61788-19 has been prepared by IEC technical committee 90: Superconductivity.

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

| FDIS | Report on voting |
|---|---|
| 90/328/FDIS | 90/330/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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- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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# INTRODUCTION

The Cu/$Nb_3Sn$ superconductive composite wires are multifilamentary composite materials. They are manufactured in different ways. The first method is the bronze route, where fine Nb / Nb alloy filaments are embedded in a bronze matrix, a barrier and a copper stabilizer. The second is the internal-tin method, where fine multifilaments are composed with copper matrix including Sn reservoirs, a barrier, and a copper stabilizer. The third is the powder-in-tube method, where Nb / Nb alloy tubes are filled with Sn rich powders and are embedded in a Cu stabilizing matrix.

Common to all types of $Nb_3Sn$ composite wires is that the superconducting A15 phase $Nb_3Sn$ has been formed at final wire dimension by applying one or more heat treatments for several days with a temperature at the last heat treatment step of around 640 °C or above. This superconducting phase is very brittle and failure of filaments occurs – accompanied by the degradation of the superconducting properties.

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. This can be done either by winding the superconductor on a spool and applying the heat treatment together with the spool afterwards (wind and react) or by heat treatment of the conductor before winding the magnet (react and wind). While the magnet is being manufactured, complicated stresses are applied to its windings. Therefore the react and wind method is the minority compared to the wind and react manufacturing process.

In the case that the mechanical properties should be determined in the unreacted, non-superconducting stage of the composite, one should also apply this standard or alternatively IEC 61788-6 (*Superconductivity – Part 6: Mechanical properties measurement – Room temperature tensile test of Cu/Nb-Ti composite superconductors*).

While the magnet is being energized, a large electromagnetic force is applied to the superconducting wires because of their high current density. In the case of the react and wind manufacturing technique, the winding strain and stress levels are very restricted.

It is therefore a prerequisite to determine the mechanical properties of the superconductive reacted $Nb_3Sn$ composite wires of which the windings are manufactured.

# SUPERCONDUCTIVITY –

# Part 19: Mechanical properties measurement – Room temperature tensile test of reacted $Nb_3Sn$ composite superconductors

## 1 Scope

This part of IEC61788 covers a test method detailing the tensile test procedures to be carried out on reacted $Cu/Nb_3Sn$ composite superconducting wires at room temperature.

The object of this test is to measure the modulus of elasticity and to determine the proof strength of the composite due to yielding of the copper and the copper tin components from the stress versus strain curve.

Furthermore, the elastic limit, the tensile strength, and the elongation after fracture can be determined by means of the present method, but they are treated as optional quantities because the measured quantities of the elastic limit and the elongation after fracture have been reported to be subject to significant uncertainties according to the international round robin test.

The sample covered by this test procedure should have a bare round or rectangular cross-section with an area between 0,15 $mm^2$ and 2,0 $mm^2$ and a copper to non-copper volume ratio of 0,2 to 1,5 and should have no insulation.

## 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 at <http://www.electropedia.org>)

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 extensometer systems 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**
***R***
tensile force divided by the original cross-sectional area at any moment during the test

### 3.2
**strain**
***A***
displacement increment divided by initial gauge length of extensometers at any moment during the test

### 3.3
**modulus of elasticity**
***E***
gradient of the straight portion of the stress-strain curve in the elastic deformation region

### 3.4
**extensometer gauge length**
length of the parallel portion of the test piece used for the measurement of displacement by means of an extensometer

### 3.5
**distance between grips**
$L_g$
length between grips that hold a test specimen in position before the test is started

### 3.6
**0,2 % proof strength**
$R_{p0,2}$
stress value where the ductile components yield by 0,2 %.

Note 1 to entry: The designated proof strengths, $R_{p0,2\text{-}0}$ and $R_{p0,2\text{-}U}$ correspond to point A or point C obtained from unloading slope *U* between 0,3 % and 0,4 % in Figure 1(a), respectively. This strength is regarded as a representative 0,2 % proof strength of the composite.

### 3.7
**tensile strength**
$R_m$
tensile stress corresponding to the maximum testing force

### 3.8
**tensile stress at elastic limit**
$R_{elasticmax}$
tensile force divided by the original cross-sectional area at the transition of elastic to plastic deformation

### 3.9
**strain at elastic limit**
$A_{elasticmax}$
strain at the transition of elastic to plastic deformation

Note 1 to entry: The stress $R_{elasticmax}$ and the corresponding strain $A_{elasticmax}$ refer to point G in Figure A.6 o0f Annex A.5 and are regarded as the transition point of elastic to plastic deformation.

## 4 Principles

The test consists of straining a test piece by tensile force beyond the elastic deformation regime, in principle for the purpose of determining the modulus of elasticity ($E$) and the proof strengths of $R_{p0,2}$.

## 5 Apparatus

### 5.1 General

The test machine and the extensometers 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 stroke speed shall be used. Grips shall have a structure and strength appropriate for the test specimen and shall be constructed to provide a firm 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 screw type, pneumatically, or hydraulically actuated.

### 5.3 Extensometer

The mass of the extensometer shall be 30 g or depending on wire diameter even less, so as not to affect the mechanical properties of the brittle reacted superconductive wire. The mass of the extensometers had to be balanced symmetrically around the wire to avoid any non-alignment force (see Clause A.2). Care shall also be taken to prevent bending moments from being applied to the test specimen.

Depending on the employed strain measuring method, however, the quantities determined by the present test should be limited. When using the conventional single extensometer system, the determination of $E_U$ and $R_{p0,2\text{-}U}$ is recommended. On the other hand, it is possible to determine all quantities described here by using an averaging double extensometer system, because of its capability to compensate the bending effects of the reacted sample and to guarantee a proper determination of the modulus of elasticity $E_0$.

NOTE Further information is given in Clauses A.2 and A.3.

## 6 Specimen preparation

### 6.1 General

The wire should be straightened before heat treatment and should be inserted into a ceramic or quartz tube with slightly larger inner diameter referring to the wire size.

The constant temperature zone length of the heat treatment furnace shall be longer than the total length mentioned below in 6.2.

Care shall be taken to prevent bending or pre-loading when the reacted specimen is manually handled during removal from the ceramic or quartz tube and mounting.

### 6.2 Length of specimen

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

### 6.3 Removing insulation

If the test specimen surface is coated with an insulating material, the coating shall be removed before the heat treatment. Either a chemical or mechanical method shall be used with care taken not to damage the specimen surface (see Clause A.7).

### 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.8).

## 7 Testing conditions

### 7.1 Specimen gripping

When the test specimen is mounted on the grips of the tensile machine, the test specimen and tensile loading axis shall be on a single straight line with a minimum of machine/specimen mismatch. Gripping techniques of specimen are described in Clause A.9.

### 7.2 Setting of extensometer

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.

During mounting care should be taken not to pre-load the specimen. After installation, loading shall be physically zeroed.

Double extensometer shall be mounted symmetrically around the cross-section to allow averaging of the strain to compensate the bending effects.

To guarantee best performance of the stress-strain curve of rectangular wires the extensometer should be mounted in such a way that strain is measured symmetrically on the small sides of the wire.

### 7.3 Testing speed

The tensile tests shall be performed with displacement control. The machine crosshead speed is recommended to be set between 0,1 mm/min and 0,5 mm/min.

### 7.4 Test

Following this procedure the tensile machine shall be started after the crosshead speed has been set to a specific level. The signals from the extensometers and the load cell shall be recorded, saved, and plotted on the abscissa and ordinate of the diagram as shown in Figures 1 (a) and 1 (b). When the total strain has reached a value between 0,3 % and 0,4 % the tensile force shall be reduced by 30 % to 40 % without changing the crosshead speed. Following this procedure the wire shall be reloaded again until final fracture.

Prior to the start of any material test program it is advisable to check the complete test equipment using similar size wires of known elastic properties (See Clause A.14).

## 8 Calculation of results

### 8.1 Modulus of elasticity ($E$)

Modulus of elasticity shall be calculated in general using the following formula and the straight portion of the unloading curve and of the initial loading one. Appropriate software for data evaluation should be used for post analyses of the plotted data with the possibility of enlargement of the stress versus strain graph, especially around the region where the deviation from linearity is expected.

$$E = \Delta F / (S_0 \Delta A) \qquad (1)$$

where

$E$ is the modulus of elasticity;

$\Delta F$ is the increment of the corresponding force;

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

$S_0$ is the original cross–sectional area of the test specimen. Since unloading process is carried out at the strain indicated by the point $A_U$ in Figure 1(a), the same Formula (1) is used for both the unloading modulus of elasticity ($E_U$) and the initial loading one ($E_0$). It is recommended to measure the unloading curve at the starting point $A_U$, where $A_U$ is recommended to be between 0,3 % and 0,4 %.

The modulus of elasticity determined from the unloading curve is expressed as $E_U$ which is given by the slope of the line ($U$ between 0,3 % and 0,4 % strain) in Figure 1(a) and that from the initial loading curve is expressed as $E_0$ by the zero offset line.

It should be, however, noted that the straight portion of the initial stress – strain curve is very narrow as indicated in Figure A.6 of Clause A.5. To measure this quantity with a low relative standard uncertainty the only currently possible technique is the use of an averaging double extensometer system. In this sense, the quantity of $E_U$ should be a representative data for the present text, while $E_0$ should be reported only when the measure is performed by means of double extensometer system.

After the test, the results shall be examined using the ratio $E_0/E_U$. The ratio shall satisfy the condition as given in Equation 2 in which $\Delta = 0,3$ (see Clause A.12).

$$1\text{-}\Delta < E_0/E_U < 1+\Delta \qquad (2)$$

When it does not satisfy the condition, the test is judged not to be valid. Then the test shall be repeated after the experimental procedure is reexamined according to the present test method.

It is guided to achieve the unloading-reloading procedure as follows: when the loading curve arrives at the strain $A_U$ (between 0,3 % and 0,4 %), the stress is reduced to $r_{umin}$ of the maximum stress (stress position where the unloading started $r_{umax}$) and then the wire is reloaded. The slope of the unloading curves shall be obtained in the linear portion between the stress $r_{umax}$ and $r_{umin}$.

NOTE 3 Typical range of $r_{umax}$ is 99 % of the maximum stress (stress where the unloading starts). The range of $r_{umin}$ is at 90 % referring to the onset of the unloading stress (see Figure 1 (b)).

### 8.2 0,2 % proof strength ($R_{p0,2\text{-}0}$ and $R_{p0,2\text{-}U}$)

The 0,2 % proof strength of the composite is determined in two ways from the unloading/reloading and initial loading part of the stress-strain curve as shown in Figures 1(a) and 1(b).

The 0,2 % proof strength of the composite under unloading $R_{p0,2\text{-}U}$ shall be determined as follows: the linear portion of the unloading slope is moved parallel to the origin of the fitted curve, which may include a negative strain value. Thereafter, a parallel line shall be shifted to 0,2 % on the abscissa from this strain point. The intersection of this line U with the stress-strain curve determines the point C that shall be defined as the 0,2 % proof strength. Depending of the unloading line (e. g. $U_{0,35}$ in Fig 1(a)), 0,2 % proof strength ($R_{p0,2\text{-}U}$) is determined.

The 0,2 % *pr*oof strength under loading $R_{p0,2\text{-}0}$ shall be determined as follows: the initial linear portion at zero offset position of the loading line of the stress-strain curve is moved 0,2 % along the strain axis 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.

Each of 0,2 % proof strength value shall be calculated using the formula (3) given below:

$$R_{p0,2-i} = F_i / S_0 \qquad (3)$$

where

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

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

as $i$ = 0 or U.

## 9 Uncertainty of measurand

Unless otherwise specified, measurements shall be carried out in a temperature that can range from 283 K to 308 K. A force measuring cell with the relative standard uncertainty less than 0,1 %, valid between zero and the maximum force capacity of load cell shall be used. The extensometers should have the relative standard uncertainty of strain less than 0,05 %. The displacement measuring transducer (e.g. LVDT [linear variable differential transformer]) used for the calibration should have the relative standard uncertainty less than 0,01 %.

The relative standard uncertainty values of measured moduli of elasticity $E_0$ *and* $E_U$ and the proof strengths $R_{p0,2\text{-}0}$ *and* $R_{p0,2\text{-}U}$ currently achieved with respect to the international round robin test of eleven representative research groups are given in Table A.1 (see Clause A.12).

According to the international round robin test (see (9) of Clause A.15), the relative standard uncertainty was reported to be 1,4 % for $E_0$ for the test data of $N$ = 17 in average after the qualification check. Similarly, 1,3 % *f*or $E_U$ ($N$ = 15), 1,5 % for $R_{p0,2\text{-}0}$ ($N$ = 17) and 2,5 % *f*or $R_{p0,2\text{-}U}$ ($N$ = 13) were reported.

## 10 Test report

### 10.1 Specimen

The following information shall be reported:

a) Name of the manufacturer of the specimen
b) Classification and/or symbol