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INTERNATIONAL STANDARD

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

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SUPERCONDUCTIVITY –

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

FOREWORD

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

This second edition cancels and replaces the first edition published in 2000. It constitutes a technical revision.

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

– the minimum distance between grips was changed from 100 mm to 60 mm;
– accuracy and precision statement were converted to uncertainty statements.

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

FDIS	Report on voting
90/207/FDIS	90/209/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 maintenance result 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- withdrawn;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

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.

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^2 to 2 mm^2 and a copper to superconductor volume ratio of 1,0 to 8,0 and without the insulating coating.

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, *International Electrotechnical Vocabulary (IEV) – Part 815: Superconductivity*

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

ISO 6892, *Metallic materials – Tensile testing at ambient 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, 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** (R_m)
tensile stress corresponding to the maximum testing force

NOTE The symbol σ_{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 %, of which value 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 strain rate 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_o)

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 between one-tenth and one-third 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 testing 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.

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 (point A) 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:

$$R_{p0,2i} = F_i \,/\, S_o \tag{1}$$

where

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

F_i is the force (N) at each point;

S_o 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.

$$E = \Delta F\ (1 + \varepsilon_a)/(S_o\ \Delta\varepsilon) \tag{2}$$

where

E is the modulus of elasticity (MPa);

ΔF is the increments (N) of the corresponding force;

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

ε_a is the strain just after unloading as shown in Figure 1.

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

9 Uncertainty

Unless otherwise specified, measurements shall be carried out 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. The estimated uncertainties for moduli of elasticity E_o and E_a, are 8 % and 2 % respectively. For 0,2 % proof strengths $R_{p0,2A}$ and $R_{p0,2B}$ smaller uncertainty values are expected due to the nearly 1/3 of the slope value of the stress strain curve in the region of intersections between shifted elastic moduli slope line and stress versus strain curve (see Figure 1).

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

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 ε_a)

The following information shall be reported as necessary.

d) Second type of 0,2 % proof strength ($R_{p0,2C}$)

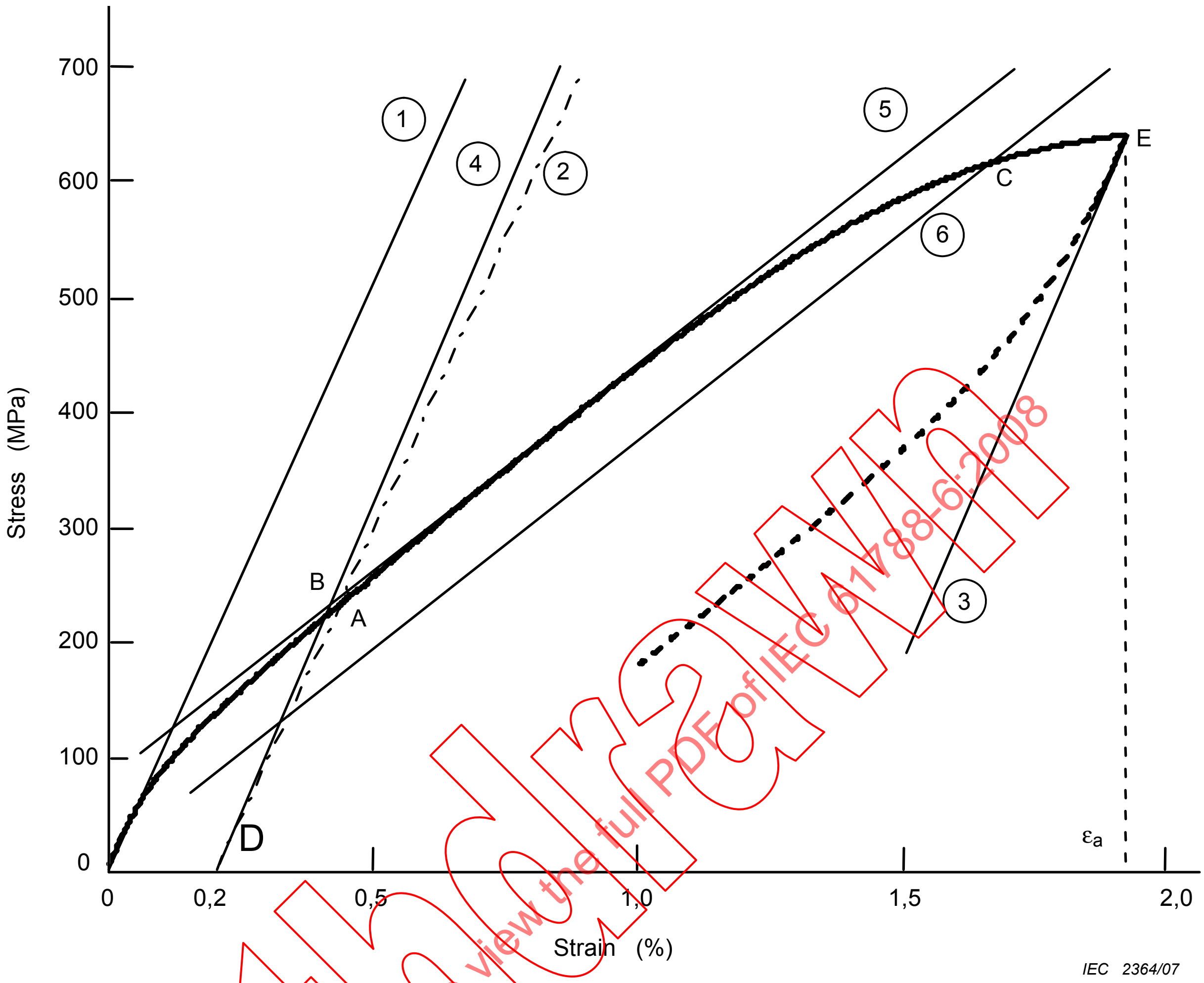
e) Percentage elongation after fracture (A)

10.3 Test conditions

a) Strain rate
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



Key

① Initial loading line

② 0,2 % offset line for initial loading line

③ Unloading line

④ 0,2 % offset line for unloading line

⑤ Second linear part for loading line

⑥ 0,2 % offset line for second linear part

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

Annex A
(informative)

Additional information relating to Clauses 1 to 10

This annex gives reference information on the variable factors that can seriously affect the tensile test methods, together with some precautions to be observed when using the standard.

A.1 Percentage elongation after fracture (A)

In Cu/NbTi superconductive wires there is a difference in strength between the copper and NbTi, and the wire is often deformed in waves by the shock of fracture. In such a case, it is difficult to find the elongation accurately after fracture using the butt method. Hence, the measurement of elongation after fracture should serve only as a reference. The movement of the cross-head may be used to find the approximate value for elongation after fracture, instead of using the butt method, as shown below. To use this method, the cross-head position at fracture must be recorded. Use the following formula to obtain the elongation after fracture, given in percentage.

$$A = 100\ (L_u - L_c) / L_c \tag{A.1}$$

where

A is the percentage elongation after fracture;

L_c is the initial distance between cross-heads;

L_u is the distance between cross-heads after fracture.

A.2 Second type of 0,2 % proof strength ($R_{p0,2C}$)

The second type of 0,2 % proof strength, at which the Nb-Ti component yields, is defined reasonably on the basis of the rule-of-mixture for the bimetallic composite including continuous filaments. As indicated in Figure 1, it should be the stress $R_{p0,2C}$ corresponding to point C, at which the straight portion of the loading curve after the point A is moved by 0,2 % along the strain axis intersects the stress-strain curve. The relevant straight portion is usually observed for the commercial Cu/Nb-Ti superconductive wires, because the copper component deforms plastically in a linear behaviour. Often the stress-strain curve does not show any straight line, but is rounded off for some wires, when they have high copper/non-copper ratio and are highly cold worked. It has been empirically made clear that the rounded-off appearance is observed when the following k-factor is less than 0,4:

$$k = (R_m - R_{p0,2A}) / R_{p0,2A} \tag{A.2}$$

The $R_{p0,2C}$ is one of the important parameters describing the mechanical property of the composite material in the scientific viewpoint, but its use is not always demanded in the engineering sense.

A.3 Extensometer

When using a special type of extensometer, which is attached with an unremovable spacer for determining the gauge length, it may introduce a problem during the unloading of the wire to zero force. To avoid a compressive force on the spacer, the actual gauge length must be adjusted during installation with sufficient clearance. If the clearance after unloading is not negligible, it must be included in calculating the strain values.

If the test specimen is thin and the extensometer is relatively heavy, any bending moment caused by the weight of the extensometer can stress the specimen, eventually resulting in the specimen yielding. To avoid this, a light extensometer with a balance weight is to be carefully attached. Alternatively, a sufficiently light extensometer without a balance weight is also acceptable to use. Figure A.1 shows an extensometer made with a Ti alloy, with a total mass of about 3 g. It is so light that even a single use without a balance weight could provide enough uncertainty according to the procedure of the present standard. Figure A.2 shows one of the lightest extensometers commercially available, with a total mass of 31 g together with a balance weight. Using it, a round robin test (RRT) was conducted in Japan and good results were obtained. The results were used to establish the present international standard.

NOTE Further information about extensometers is obtainable from the Japanese National Committee of IEC/TC90, ISTEC, Minato-ku, Shinbashi 5-34-3, Tokyo 105-0004, Japan, Tel 81 (03)3431-4002, Fax 81(03)3431-4044, e-mail "Yasuzo Tanaka" <tc90tanaka@istec.or.jp>

Since the superconductive composite wire is covered with a soft copper, a scratch in the surface of the specimen made as it is mounted can be a starting point of fracture. Care should therefore be taken when handling the specimen.

A.4 Insulating coating

The coating on the surface of the test specimen should be removed using an appropriate organic solvent that would not damage the specimen. If the coating material is not dissolved by the organic solvent, a mechanical method should be used with care to prevent the copper from being damaged. If the coating is not removed, it affects the strength to only a small extent. For example, tensile strength decreases by less than 3 % for a low-strength wire which has a high copper ratio of 7. The coating is not designed as a structural component. An analysis of measurement as a three-component composite, i.e. copper, Nb-Ti and insulating coating, is too complicated to conduct. Therefore this test method covers a bare wire in order to maintain uncertainty.

A.5 Cross-sectional area

Where even lower uncertainty is required, the cross-sectional area may be obtained by correcting the radius of the corner of the rectangular wire finished by dies, using the value given on the manufacturing specifications. For rolling or Turk's-head finish, the radius of the corner is not controlled and a correction is made using a microphotograph of the cross-section.

A.6 Gripping force

A weak gripping force results in slippage and a strong gripping force can break the gripped surface. Care should therefore be used when adjusting the gripping force.

A.7 Uncertainty

The magnitude of the COV for the experimental data mentioned in Clause 9 is based on the guideline proposed by the Japanese National Committee of IEC TC 90. JNC fulfilled the domestic round robin test (RRT) in 1996 by contributions from eight research organizations [1]1). Comparing the result with a variety of experimental conditions, a realistic level of uncertainty according to the present test method has been determined [2].

The modulus of elasticity E_o determined under the loading curve has been found to be always smaller than the modulus E_a under unloading. The uncertainty to E_o is fairly high as shown by a COV of 35 %. The reason why the E_o is so small and scattered compared with the E_a, is

1) Figures in square brackets refer to the reference documents in Clause A.8 of this Annex.

attributed to the following handling issues: the bending of the wire specimen, the misalignment of sample gripping with respect to the load axis and a week grip, and so on. Also, it is pointed out that the copper component is in a plastic state at room temperature before the test, depending on a degree of thermal contraction during cooling from the heat treating temperature. As a whole, the initial loading curve with non-linearity causes the result of $E_o < E_a$.

The German National Committee of the IEC reported that the modulus of elasticity could be determined with a COV of 4 % by adopting an initial linear loading at zero-offset. This low COV was achieved by using two light extensometers (Figure A.1) which enabled the cancelling of the possible initial bending effects and ensured a high degree of linearity for the zero-offset loading line.

Care must be taken while handling specimens in order not to induce strain to the copper component. Otherwise, the 0,2 % proof strength of the composite due to yielding of the copper component would increase due to work hardening. Allowable pre-loading limit should be taken into consideration in this line. According to the result of RRT, it is made clear that $R_{p0,2A} > R_{p0,2B}$ holds together with the COV for $R_{p0,2A}$ > the COV for $R_{p0,2B}$. As mentioned in the above paragraph, the result of $E_o < E_a$ is in accordance with $R_{p0,2A} > R_{p0,2B}$.

The second type of 0,2 % proof strength $R_{p0,2C}$ is the quantity determined with the lowest uncertainty, that should serve only as reference. Its COV has been reported to be 3 %. Care must, however, be taken to ensure an existence of a straight portion in the stress-strain curve after the point A in Figure 1.

As mentioned in Clause A.1, the percentage elongation after fracture determined by the crosshead method is assessed only as a reference value because a large COV (36 %) has been reported and this variability is too high.

A.8 Reference documents

[1] SHIMADA, M., HOJO, M., MORIAI, H. and OSAMURA. K. *Jpn. Cryogenic Eng*, 1998, 33, p. 665.

[2] OSAMURA, K., NYILAS, A., SHIMADA, M., MORIAI, H., HOJO, M., FUSE T. and SUGANO, M. Adv. Superconductivity, 1999, XI, p.1515.

Dimensions in millimetres

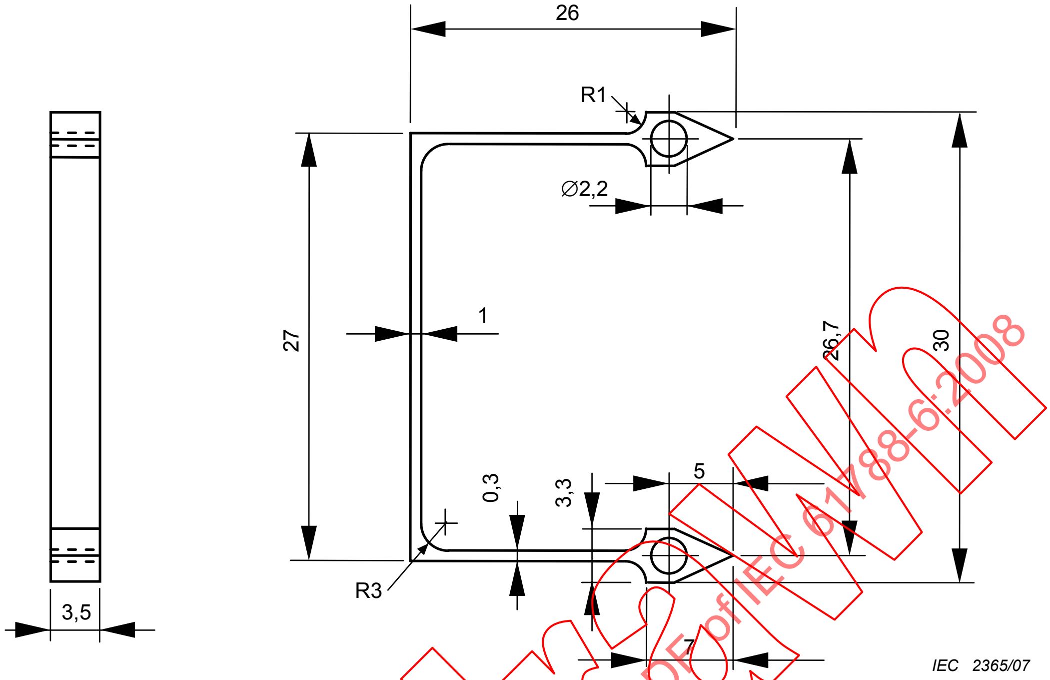


Figure A.1 – An example of the light extensometer, where R1 and R3 indicate the corner radius

Dimensions in millimetres

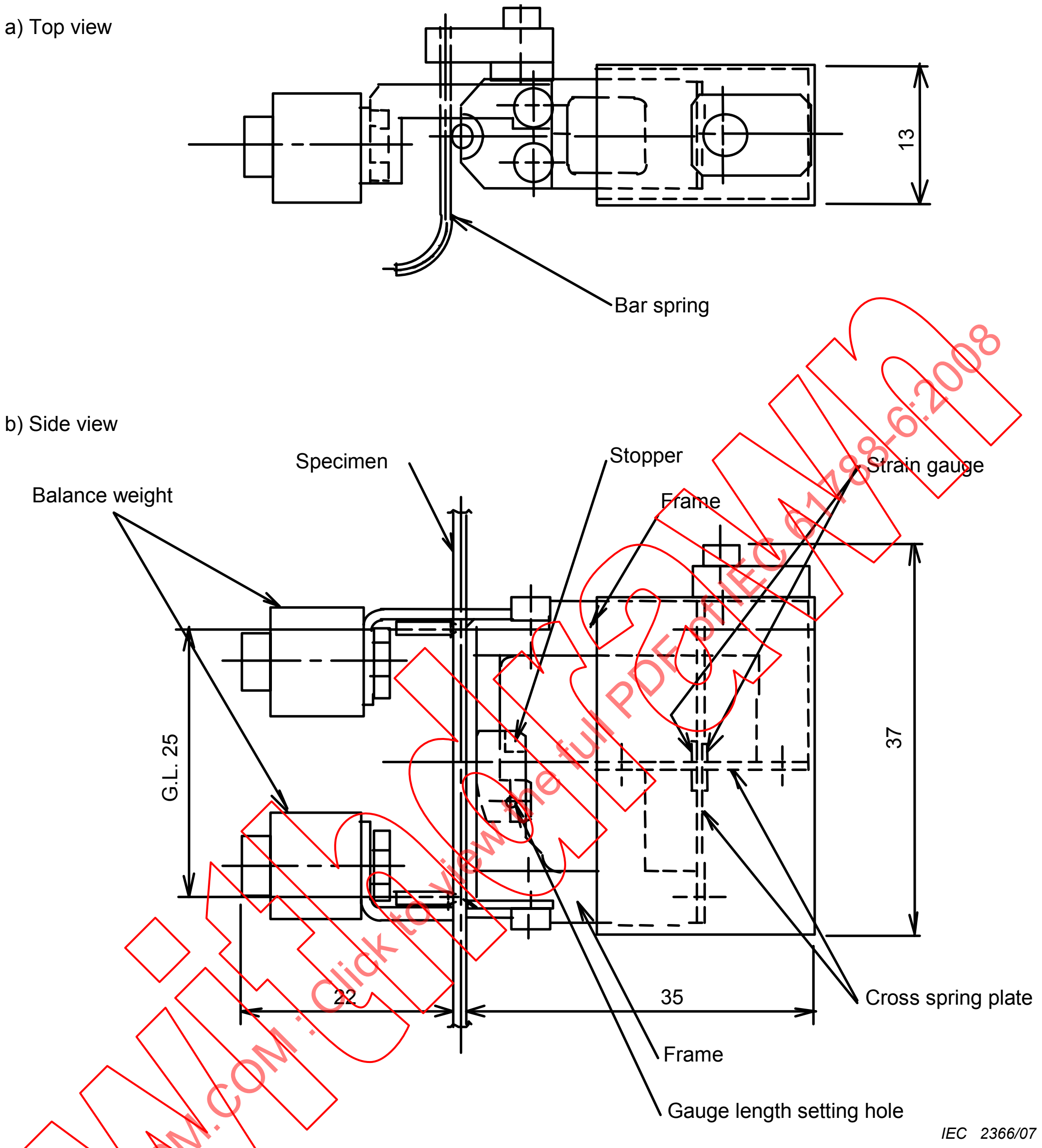


Figure A.2 – An example of the extensometer provided with balance weight and vertical specimen axis

Annex B
(informative)

Uncertainty considerations

B.1 Overview

In 1995, a number of international standards organizations, including IEC, decided to unify the use of statistical terms in their standards. It was decided to use the word “uncertainty” for all quantitative (associated with a number) statistical expressions and eliminate the quantitative use of “precision” and “accuracy.” The words “accuracy” and “precision” could still be used qualitatively. The terminology and methods of uncertainty evaluation are standardized in the Guide to the Expression of Uncertainty in Measurement (GUM) [1][2].

It was left to each TC to decide if they were going to change existing and future standards to be consistent with the new unified approach. Such change is not easy and creates additional confusion especially for those who are not familiar with statistics and the term uncertainty. At the June 2006 TC 90 meeting in Kyoto, it was decided to implement these changes in future standards.

Converting “accuracy” and “precision” numbers to the equivalent “uncertainty” numbers requires knowledge about the origins of the numbers. The coverage factor of the original number may have been 1, 2, 3, or some other number. A manufacturer’s specification that can sometimes be described by a rectangular distribution will lead to a conversion number of $1/\sqrt{3}$. The appropriate coverage factor was used when converting the original number to the equivalent standard uncertainty. The conversion process is not something that the user of the standard needs to address for compliance to TC 90 standards, it is only explained here to inform the user about how the numbers were changed in this process. The process of converting to uncertainty terminology does not alter the user’s need to evaluate their measurement uncertainty to determine if the criteria of the standard are met.

The procedures outlined in TC 90 measurement standards were designed to limit the uncertainty of each influence quantity based on the Convener’s engineering judgment and propagation of error analysis. Where possible, the standards have simple limits for some influence quantities that do not require the user to evaluate the uncertainty of this quantity. The overall uncertainty of a standard was then confirmed by an interlaboratory comparison.

B.2 Definitions

Statistical definitions can be found in three sources: the GUM, the International Vocabulary of Basic and General Terms in Metrology (VIM)[2], and the NIST Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results (NIST)[3]. Not all statistical terms used in this standard are explicitly defined in the GUM. For example, the terms “relative standard uncertainty” and “relative combined standard uncertainty” are used in the GUM (5.1.6, Annex J), but they are not formally defined in the GUM (see [3]).

B.3 Uncertainty evaluation example for TC 90 standards

The observed value of a measurement often does not coincide exactly with the true value of the measurand. The observed value may be considered as an estimate for the true value. This measurement uncertainty is part of the "measurement error" and an inherent part of any measurement. Therefore, the uncertainty of the result demonstrates the metrological quality of the measurements by additionally improving the knowledge about the measurement procedure. The result of any physical measurement comprises two parts: an estimate of the

[2] Figures in square brackets refer to the reference documents in Clause B.4 of this Annex.