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INTERNATIONAL STANDARD

Optical fibres –
Part 1-31: Measurement methods and test procedures – Tensile strength

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OPTICAL FIBRES –

Part 1-31: Measurement methods and test procedures – Tensile strength

FOREWORD

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International Standard IEC 60793-1-31 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition published in 2001. This edition constitutes a technical revision.

The main change with respect to the previous edition is the addition of comprehensive details, such as examples of fibre clamping as given in Annexes A, B and C.

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

CDV	Report on voting
86A/1285/CDV	86A/1308/RVC

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 60793-1series, published under the general title *Optical fibres – Measurement methods and test procedures*, 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- withdrawn,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.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

Failure stress distributions can be used to predict fibre reliability in different conditions. IEC/TR 62048 shows mathematically how this can be done. To complete a given reliability projection, the tests used to characterize a distribution shall be controlled for the following:

- Population of fibre, e.g., coating, manufacturing period, diameter
- Gauge length, i.e., length of section that is tested
- Stress or strain rates
- Testing environment
- Preconditioning or aging treatments
- Sample size

This method measures the strength of optical fibre at a specified constant strain rate. It is a destructive test, and is not a substitute for prooftesting.

This method is used for those *typical* optical fibres for which the median fracture stress is greater than 3,1 GPa (450 kpsi) in 0,5 m gauge lengths at the highest specified strain rate of 25 %/min. For fibres with lower median fracture stress, the conditions herein have not demonstrated sufficient precision.

Typical testing is conducted on “short lengths”, up to 1 m, or on “long lengths”, from 10 m to 20 m with sample size ranging from 15 to 30.

The test environment and any preconditioning or aging is critical to the outcome of this test. There is no agreed upon model for extrapolating the results for one environment to another environment. For failure stress at a given stress or strain rate, however, as the relative humidity increases, failure stress decreases. Both increases and decreases in the measured strength distribution parameters have been observed as the result of preconditioning at elevated temperature and humidity for even a day or two.

This test is based on the theory of fracture mechanics of brittle materials and on the power-law description of flaw growth (see IEC TR 62048). Although other theories have been described elsewhere, the fracture mechanics/power-law theory is the most generally accepted.

A typical population consists of fibre that has not been deliberately damaged or environmentally aged. A typical fibre has a nominal diameter of 125 µm, with a 250 µm or less nominal diameter acrylate coating. Default conditions are given for such typical populations. Atypical populations might include alternative coatings, environmentally aged fibre, or deliberately damaged or abraded fibre. Guidance for atypical populations is also provided.

OPTICAL FIBRES –

Part 1-31: Measurement methods and test procedures – Tensile strength

1 Scope

This part of IEC 60793 provides values of the tensile strength of optical fibre samples and establishes uniform requirements for the mechanical characteristic – tensile strength. The method tests individual lengths of uncabled and unbundled glass optical fibre. Sections of fibre are broken with controlled increasing stress or strain that is uniform over the entire fibre length and cross section. The stress or strain is increased at a nominally constant rate until breakage occurs.

The distribution of the tensile strength values of a given fibre strongly depends on the sample length, loading velocity and environmental conditions. The test can be used for inspection where statistical data on fibre strength is required. Results are reported by means of statistical quality control distribution. Normally the test is carried out after temperature and humidity conditioning of the sample. However, in some cases, it may be sufficient to measure the values at ambient temperature and humidity conditions

This method is applicable to types A1, A2, A3, B and C optical fibres.

Warning – This test involves stretching sections of optical fibre until breakage occurs. Upon breakage, glass fragments can be distributed in the test area. Protective screens are recommended. Safety glasses should be worn at all times in the testing area.

2 Normative references

The following referenced documents are indispensable for the application of this document.

For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60793-1-20, *Optical fibres – Part 1-20: Measurement methods and test procedures – Fibre geometry*

IEC 60793-1-21, *Optical fibres – Part 1-21: Measurement methods and test procedures – Coating geometry*

3 Apparatus

3.1 General

This clause prescribes the fundamental requirements of the equipment used for dynamic strength testing. There are many configurations that can meet these requirements. Some examples are presented in Annex A. The choice of a specific configuration will depend on such factors as:

- gauge length of a specimen
- stress or strain rate range
- environmental conditions
- strength of the specimens.

3.2 Gripping the fibre at both ends

Grip the fibre to be tested at both ends and stretch it until failure occurs in the gauge length section. The grip shall not allow the fibre to slip out prior to failure and shall minimize failure at the grip.

Record a break that occurs at the grip, but do not use it in subsequent calculations. Since fibre strain is increasing during the test, some slippage occurs at the grip. At higher stress levels, associated with short gauge lengths, slippage can induce damage and cause gripping failures that are difficult to ascertain. The frequency of such failures can often vary with stress or strain rate. Careful inspection of the residual fibre pieces, or other means, is required to prevent the possibility of including gripping failures in the analysis.

Use a capstan, typically covered with an elastomeric sheath, to grip the fibre (see Figure A.1). Wrap a section of fibre that will not be tested around the capstan several times and secure the fibre at the ends with, for example, an elastic band. Wrap the fibre with no crossovers. The capstan surface shall be tough enough so that the fibre does not cut into it when fully loaded. The amount of slippage and capstan failures depends on the interaction of the fibre coating and the capstan surface material, thickness, and number of wraps. Careful preliminary testing is required to confirm the choice of a capstan surface.

Design the diameter of the capstan and pulley so that the fibre does not break on the capstan due to bend stress. For typical silica-clad fibres, the bend stresses shall not exceed 0,175 GPa. (For typical 125/250 µm silica fibre, the minimum capstan diameter is then 50 mm.) A particular gripping implementation is given in Annex B.

3.3 Sample support

Attach the specimen to the two grips. The gauge length is the length of fibre between the axes of the gripping capstans before it is stretched. To reduce the space required to perform the test on long gauge lengths, one or more pulleys may be used to support the specimen (see Figure A.4). The pulleys shall be designed, and their surfaces kept free of debris, so the fibre is not damaged by them. The remainder of the fibre, away from pulleys and capstans, shall not be touched.

When multiple fibres are tested simultaneously, as in Figure A.5, a baffle arrangement is required to prevent a broken fibre from snapping into, or otherwise perturbing the other fibres under test.

3.4 Stretching the fibre

Stretch the fibre at a fixed nominal strain rate until it breaks. The nominal strain rate is expressed as the percent increase in length per minute, relative to the gauge length.

There are two basic alternatives for stretching the fibre:

– Method A: Increase the separation between the gripping capstans by moving them apart at a fixed rate of speed, with the starting separation equal to the gauge length (Figure A.2 of Annex A).

– Method B: Rotate a capstan at a fixed rate to take up the fibre and strain the section between capstans (Figures A.3 to A.5 of Annex A). The rotation shall not result in crossovers on the capstan.

Calibrate the strain rate to within ±10 % of the nominal strain rate. Some equipment configurations are computer-controlled and allow dynamic control of the capstan motion to produce a constant stress rate. A particular implementation of this is given in Annex C.

The strain rate shall be agreed between customer and supplier. A strain rate range of either 2,5 % to 5 % or 15 % to 25 % is typically used.

3.5 Measuring the force at failure

Measure the tensile load (force in tension) at failure for each specimen by a calibrated load cell, to within ±1 % of the actual load. This can be done with a variety of methods:

- strip chart recorder
- peak and hold meter
- computer sampling.

Provide a means of measuring the tensile load as a function of time to determine the stress rate. This is not required for each individual test, but shall be done occasionally.

Calibrate the load cell to within 0,5 % of the failure, or maximum load, for each range of failure loads, while it is oriented in the same manner as when testing a fibre. Do this by substituting a string attached to a known weight for the test specimen. For method B, a light, low-friction pulley can be used in place of the capstan that is not attached to the load cell. The string, with one end attached to the load cell capstan and the other end attached to a known weight, shall duplicate the direction of a test specimen and be of a diameter comparable to that of a test specimen. A minimum of three calibration weights, bracketing the typical failures, is recommended.

3.6 Environmental control equipment

Measured failure stress and fatigue characteristics are known to vary with temperature and humidity of the fibre, both of which shall be controlled during both preconditioning and test. Many equipment configurations might be used to provide the required controls, including controls on the entire room in which testing is conducted.

Typical control requirements are:

- Temperature: 23 ± 2 °C
- Relative Humidity: 50 ± 5 %.

Alternative test environments, such as high non-precipitating humidity, can be achieved by enclosing the test specimen and injecting water vapour into the enclosure. Figure A.5 shows a ganged tester that includes an enclosure over a circulating water bath.

4 Sample preparation

4.1 Definition

A sample is one or more fibres from a population. Each sample provides a result by cutting it into smaller lengths called specimens. Testing results on these specimens are combined to yield an overall result for the sample. The term "sample size" is used to indicate the number of specimens tested in rest of this standard.

For ribbonized fibre, select the specimens uniformly across the ribbon structure. Exercise caution in removing fibre from the ribbon to avoid inadvertent strength reduction.

4.2 Sample size and gauge length

The result of testing is a statistical distribution of failure stress values. Hence all reported parameters are statistical in nature, with inherent variability that is a function of the sample size and the variability of flaw size within the sample. The weakest site, or largest flaw, within a specimen will fail, and the typical failure stress decreases as gauge length increases.

A given population can have flaws generated from multiple causes. An example is a bi-modal aggregate distribution as shown in the Weibull plot of Figure 1 (see also 6.2) obtained for a 20 m gauge length set-up. The narrow near vertical distribution on the right (around 5 GPa) is called the intrinsic region; the wider distribution below this 5 GPa is the extrinsic region.

Testing on gauge lengths of 0,5 m does not typically result in measuring flaws from the extrinsic region. From time to time, however, the failure stress of an extrinsic flaw is measured and appears as an "outlier". If the outlier is included in the data analysis, errors in the parameters will occur. For typical testing, uniform outlier removal techniques are recommended.

For tests which are designed to measure characteristics of the extrinsic region, large sample sizes (hundreds of specimens) and long gauge lengths (20 m) are recommended. For characterization of the intrinsic region as per this standard, a gauge length of 0,5 m is often used. For the dynamic strength, a sample size of 30 is often used. Any deviation from these values is to be specified in the detail specification.

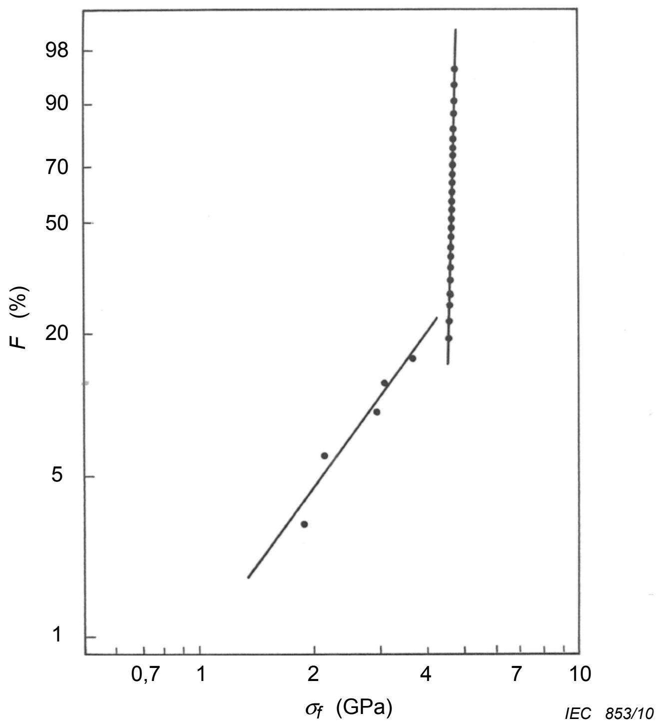

Figure 1 – Bimodal tensile strength Weibull plot for a 20 m gauge length test set-up at 5 %/min strain rate

Statistical analysis can be performed to determine whether a given precision has been achieved.

4.3 Auxiliary measurements

Failure stress calculations require a conversion of tensile load to the stress on the cross section of the glass portion of the fibre. The cladding diameter, as measured by IEC 60793-1-20, is used in this calculation to compute the cross sectional area. The coating also bears part of the tensile load that decreases the stress on the glass cross section. Subclause 6.1 contains formulas for stress calculations.

The coating correction factor is a function of the coating thickness, measured by IEC 60793-1-21 and Young's Modulus of each coating layer and the modulus of the glass.

The modulus of cured coating is often characterized by the manufacturer. For typical fibre, the contribution of coating effects is less than 5 % of total load, and compensation (hence measurement) for coating is not required (see 6.1). When this is done, the reported failure stress is larger than actual by a fixed percentage. When coating effects are compensated, average or nominal values may be used for all specimens. The contribution of coating modulus to failure stress can change with the stress or strain rate. If the contribution at any stress or strain rate is greater than 5 % of the total load, then the coating effect shall be included in the computation.

4.4 Environment

There are two key environmental considerations: aging environment and test environment.

Fibre aging is sometimes required. Even brief accelerated aging may produce increases or decreases in the measured strength of some fibres. The causes of these phenomena are not well understood. As a consequence, extrapolation methodologies from accelerated aging environments to other environments are under study.

After extensive aging, the coating surface friction may be altered. After any aging and before any testing, fibre specimens should be pre-conditioned in the test environment for at least 12 h.

The typical test environment is 23 °C (±2°) and 50 % RH (±5 %). Alternative environments, such as high non-precipitating relative humidity, can yield significantly different failure stress values.

5 Procedure

5.1 Preliminary steps

a) Age the specimens if required.

b) Precondition the specimens.

5.2 Procedure for a single specimen

a) Mount the specimen in the capstans, making sure the fibre does not cross over itself or become damaged in the gauge length by mounting.

b) Verify equipment settings for the desired nominal strain rate.

c) Re-set the tension recording display.

d) Begin capstan motion. For nominal strain rates of 0,03 %/min or less, the specimen may be pre-loaded at 0,3 %/min to about half of the expected failure stress at the slower rate. The expected failure stress may be projected from results at higher strain rates. When testing damaged fibre, pre-loading is not recommended unless the expected time to failure is in excess of 4 h.

e) At failure, stop the capstan and record the failure load and, if necessary, the stress rate.

f) Verify that the break did not occur on the capstan. If it did, mark the measurement so it will not be used in calculations.

g) Remove the residual fibre from the capstans and complete any auxiliary measurements, if necessary, as in 4.3.

5.3 Procedure for completing all samples for a given nominal strain rate

a) Record the nominal strain rate and any population identifications.

b) Determine if coating effects will be compensated. If so, record the appropriate coating parameters (see 6.1). Record the nominal cladding diameter if the nominal is used to compute stress.

c) Complete 5.2 for each specimen.

d) Using 6.1, compute the failure stress for each specimen, and sort in increasing order.

e) Complete the Weibull plot (see Figure 1), if required, using 6.2. If required, compute the Weibull parameters, m_d and S_0 using 6.3.

f) If required for handleability requirements, compute the median failure stress σ_{50} and the 15-percentile failure stress σ_{15} according to 6.2.

6 Calculations

6.1 Conversion of tensile load to failure stress

The following symbols and units are used:

- fibre dimensions µm
- gauge length m
- stress σ and failure stress σ_f GPa
- tension T and failure tension T_f N
- stress rate $\dot{\sigma}$ GPa/s

Method A:

When the load is substantially aligned with the tension, T, and D_g is the cladding diameter, Equation (1) provides the stress without compensating for the coating:

$$\sigma = \frac{4 \times 10^3 T}{\pi D_g^2} \text{ in GPa} . \tag{1}$$

Method B:

When coating is compensated, the following equations are used. Calculate the fraction

$$R = \frac{E_0 A_0}{E_0 A_0 + \sum_{j=1}^{N} E_j A_j} , \tag{2a}$$

where

E_0 is Young's modulus of the glass, typically 70,3 GPa for silica;

A_0 is the cross sectional area of the glass fibre;

For N coating layers indexed with j , E_j and A_j are the Young's modulus and layer cross sectional area, for each layer, respectively.

The coating compensated stress is given by

$$\sigma_c = \sigma R \quad . \tag{2b}$$

6.2 Preparation of a Weibull plot

Figure 1 shows a typical Weibull plot, where the line drawn through the data represents an ideal Weibull distribution. While Weibull plots are typically used to display the data for a given nominal strain rate, the actual distribution may not be Weibull.

a) Sort the failure stress values in order of increasing value.

b) Let k represent the rank of a given failure stress, e.g., k = 1, 2, 3, ..., N, and σ_{fk} be the k th failure stress.

c) Let

$$x_k = \ln \sigma_{fk} \tag{3a}$$

and

$$y_k = \ln\left[1 - \frac{k-0{,}5}{N}\right] \tag{3b}$$

d) Plot y_k versus. x_k . Label the axes with the associated probability levels and failure stress values.

NOTE The median failure stress σ_{50} and the 15-percentile failure stress σ_{15} are calculated if required.

If 0,5 N + 0,5 is an integer, $\sigma_{50} = \sigma_{0{,}5N+0{,}5}$. Otherwise, σ_{50} is determined by an appropriate interpolation between $\sigma_{0{,}5N}$ and $\sigma_{0{,}5N+1}$.

If 0,15 N + 0,5 is an integer, $\sigma_{15} = \sigma_{0{,}15N+0{,}5}$. Otherwise, σ_{15} is determined by an appropriate interpolation between $\sigma_{[0{,}15N+0{,}5]}$ and $\sigma_{[0{,}15N+0{,}5]+1}$, where square brackets stand for greatest integer function.

6.3 Computation of Weibull parameters

The Weibull distribution cumulative frequency function is given by:

$$F = 1 - \exp\left[-\left(\frac{\sigma}{S_0}\right)^{m_d}\right] \tag{4a}$$

where F corresponds with $\frac{k-0{,}5}{N}$ of Equation (3b). Consequently,

$$\ln(-y_k) = m_d \ln\left(\frac{\sigma_{fk}}{S_0}\right) \tag{4b}$$

Method A – Simple Rank Method

For the sample sizes that are typically used (see 4.1), the following method can be used. Determine the values

$$\begin{aligned} k_1 &= 0{,}15\,N + 0{,}5 \\ k_2 &= 0{,}85\,N + 0{,}5 \\ k_3 &= 0{,}5\,N + 0{,}5 \end{aligned} \tag{5}$$

Compute

$$m_{\mathrm{d}} = \frac{y_{\mathrm{k2}} - y_{\mathrm{k1}}}{x_{\mathrm{k2}} - x_{\mathrm{k1}}} \tag{6a}$$

and

$$S_0 = \exp\left[\frac{0{,}366512}{m_d} + x_{k_3}\right] \tag{6b}$$

Method B – Maximum Likelihood Estimation (MLE) method

The log of the likelihood function is

$$\ln[L(m_d, S_0)] = N ln(m_d) - N m_d ln(S_0) + (m_d - 1)\sum_{k=1}^{N} ln(\sigma_{fk}) - S_0^{-m_d} \sum_{k=1}^{N} \sigma_{fk}^{m_d} \tag{7}$$

Select m_d and S_0 to maximize Equation (7). For a given value of m_d, the optimal value for S_0 is

$$S_0 = \frac{1}{N}\sum_{k=1}^{N} \sigma_{fk}^{m_d} \ . \tag{8}$$

The optimum value for m_d is determined by an iterative method.

7 Results

7.1 The following information should be reported for each test:

- fibre identification;
- date and title;
- strength values - report the strain value under which the fibre breaks as the strength of fibre (Weibull plot and if applicable, Weibull parameter m_d and S_0).

7.2 The following information should be provided for each test:

- length of sample;
- pulling speed (strain rate);
- type of clamping fixtures;
- relative humidity and ambient temperature;
- any special conditioning.

8 Specification information

The detail specification shall specify the following information:

- any deviations to the procedure that apply.
- failure or acceptance criteria.

Annex A
(informative)

Typical dynamic testing apparatus

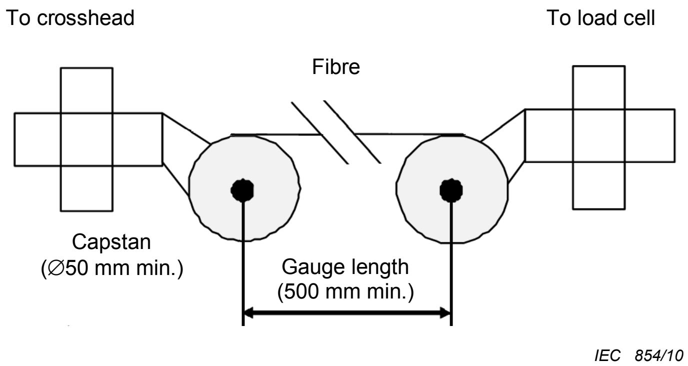

Figure A.1 – Capstan design

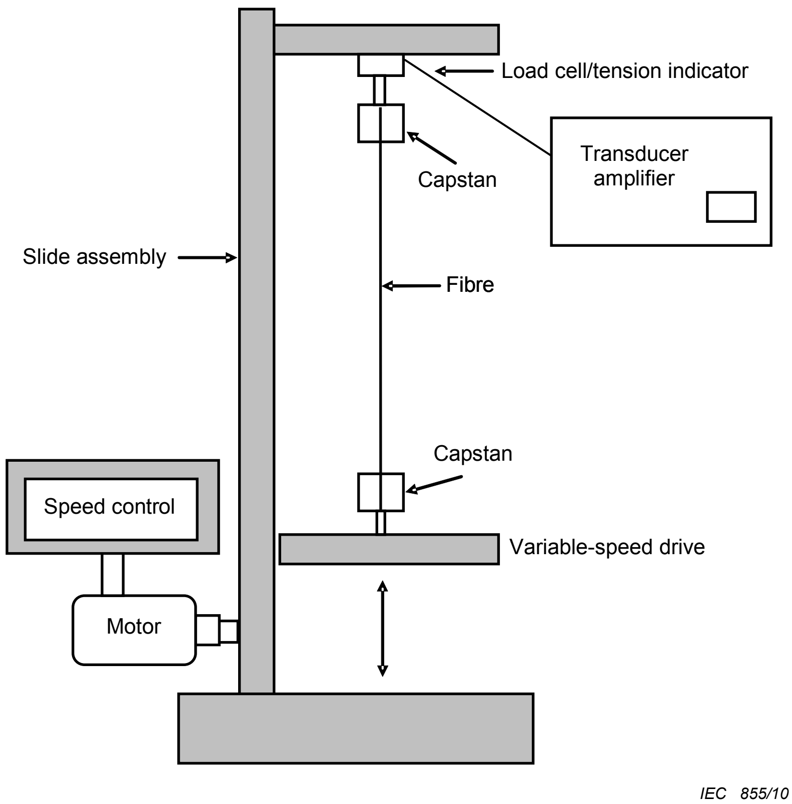

Figure A.2 – Translation test apparatus

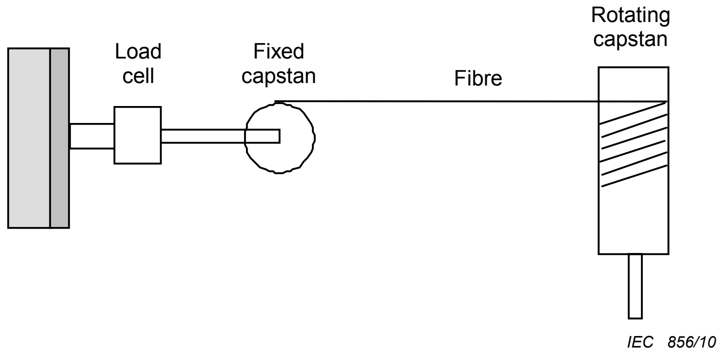

Figure A.3 – Rotating capstan apparatus

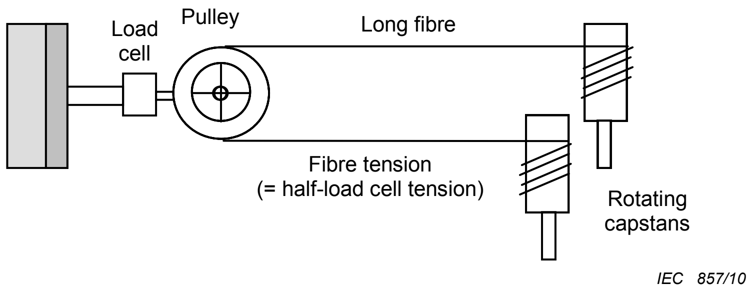

Figure A.4 – Rotating capstan apparatus for long lengths

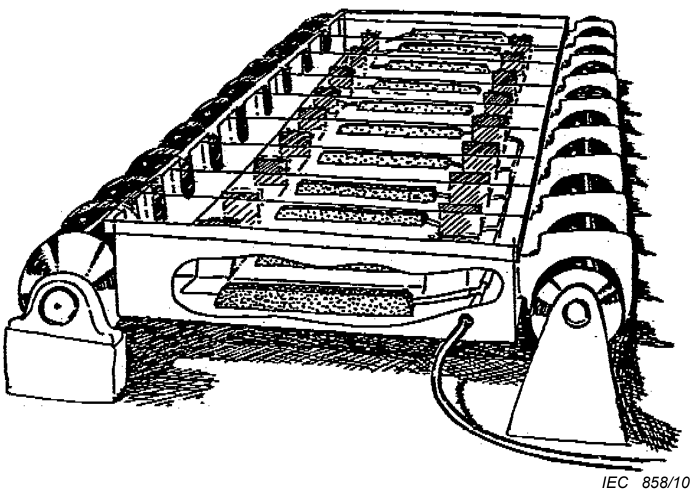

Figure A.5 – Ganged rotating capstan tester

Annex B
(informative)

Guideline on gripping the fibre

The uniform transfer of force from the capstan to the glass fibre is essential for obtaining good measurements of failure stress. Both the coating and the stress rate can alter this transfer function, depending on the capstan surface and mechanical characteristics. The quality of the transfer function can be assessed by inspecting the plot of measured force (stress) versus applied strain (time under increasing load). Figures B.1 to B.3 show results that are not acceptable. Figure B.4 shows a result that is acceptable.

NOTE Time and force (stress) scale are not indicated since these figures are only qualitative illustrations.

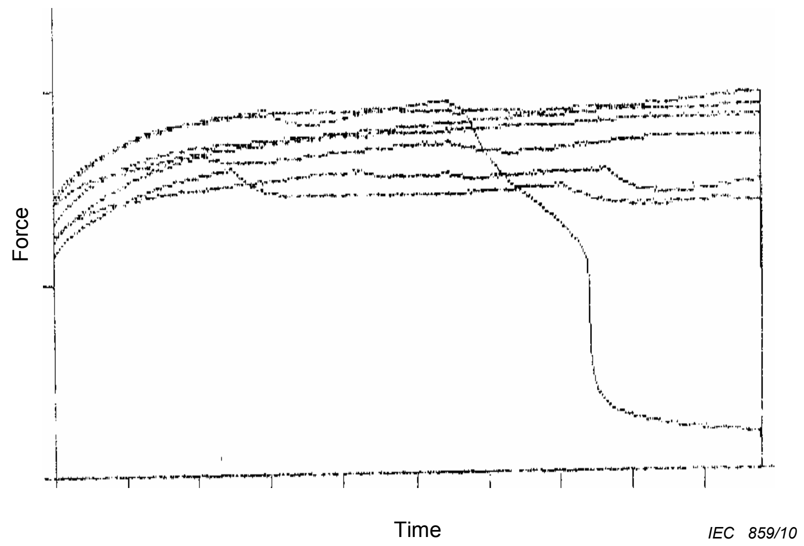

Figure B.1 – Gradual slippage

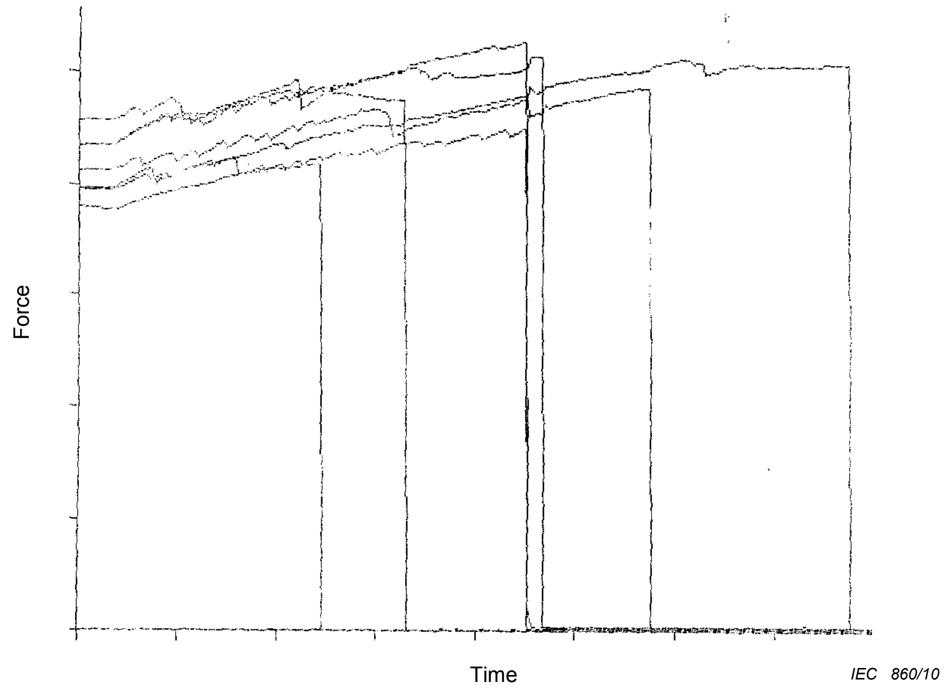

Figure B.2 – Irregular slippage

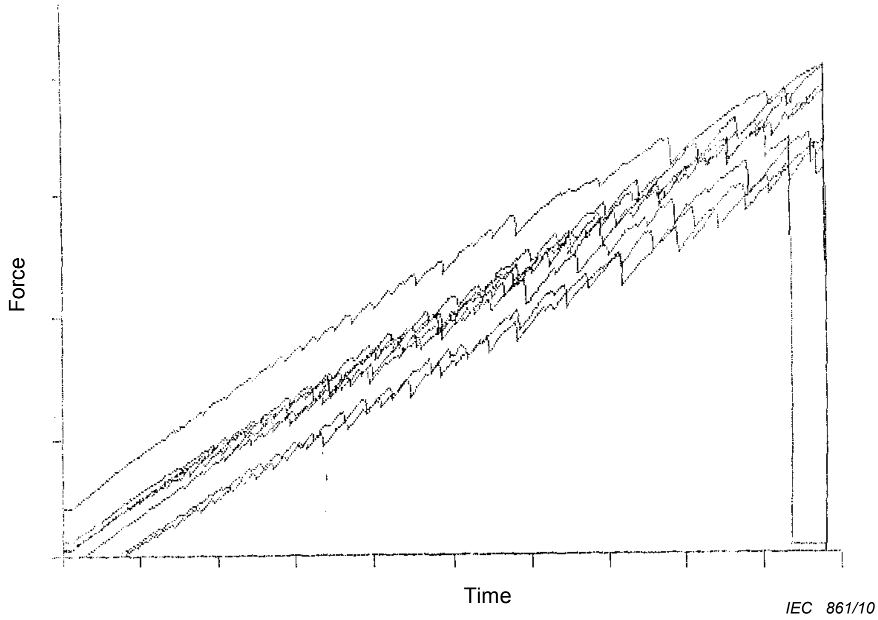

Figure B.3 – Sawtooth slippage

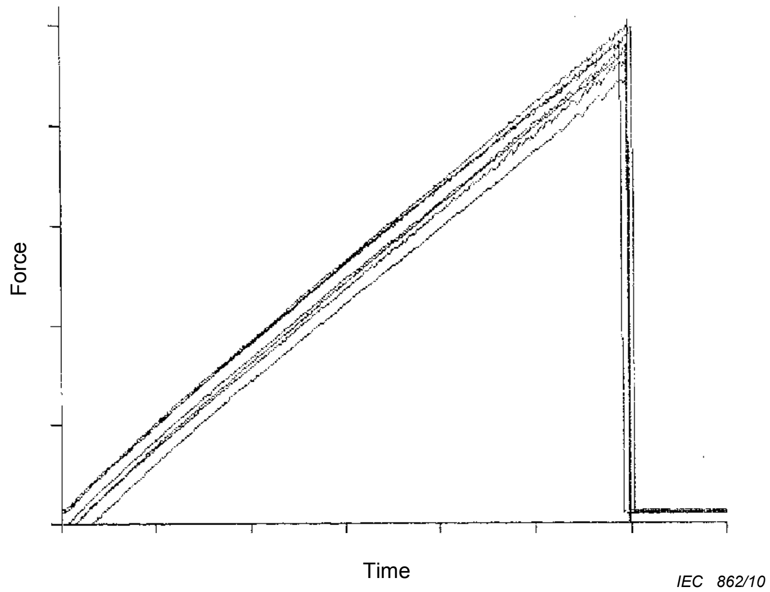

Figure B.4 – Acceptable transfer function

These results are affected by the surface of the capstan, the capstan diameter, number of wraps around the capstan, and the clamping mechanism. For some coatings, the typical capstan shown in Figure B.5, does not provide acceptable results. Alternative capstan surfaces, such as silicone, can improve the results, but subtle batch changes can lead to results shown in Figure B.1.

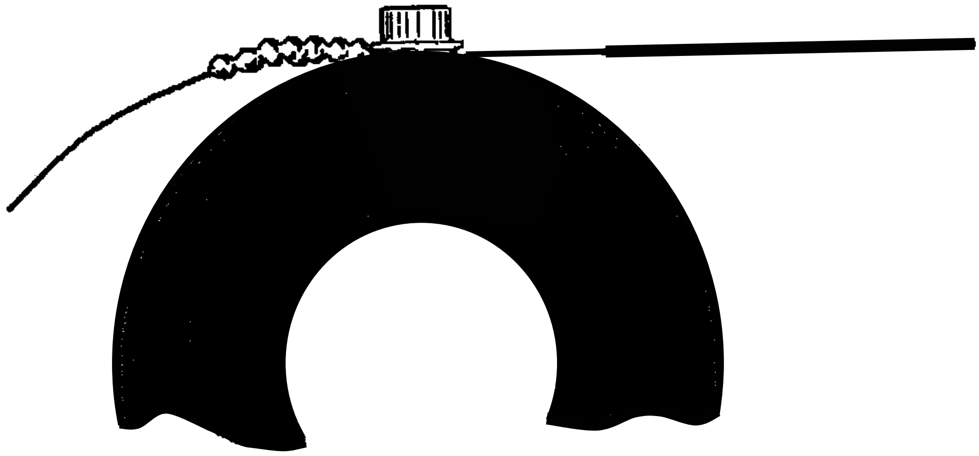

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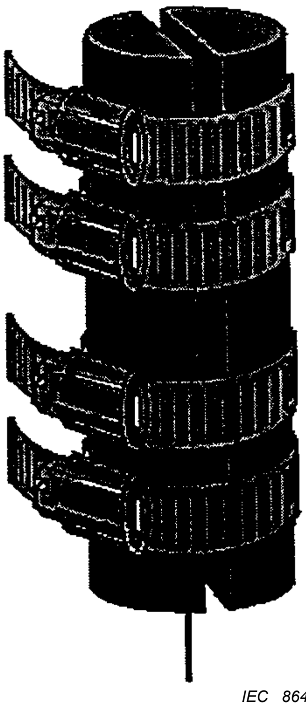
Figure B.5 – Typical capstan

Other methods have been tried. Figures B.6 and B.7 show two approaches that were found to yield better results, but which did not provide uniformly acceptable force rate plots and low incidence of gripping failures.



IEC 864/10

Figure B.6 – Isostatic compression

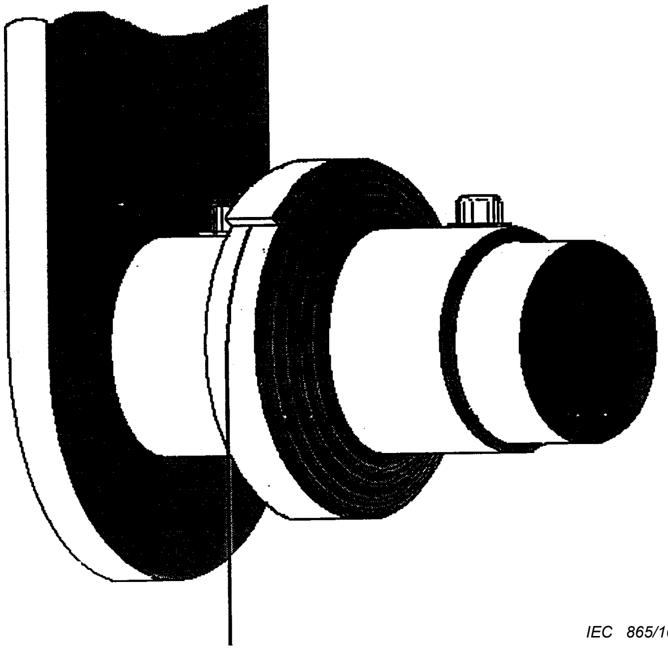


Figure B.7 – Escargot wrap

Annex C
(informative)

Guideline on stress rate

Fibre slippage or loading system compliance can be compensated for by using a servo control system similar to the one shown in Figure C.1. The fibre is attached at one end to a capstan mounted on a translation stage. The stage is moved by a computer-controlled stepper motor. The load applied to the fibre is monitored by the computer using an A/D data acquisition system. The computer software can then continuously modify the stepper motor speed to maintain the prescribed loading rate.

A double-sided adhesive foam tape is recommended for covering the capstans. Any slippage of the fibre then tends to be steady due to the viscous nature of the adhesion. Non-adhesive friction tape can lead to stick-slip conditions, and it is then difficult for the computer software to compensate for the abrupt changes in load that occur.

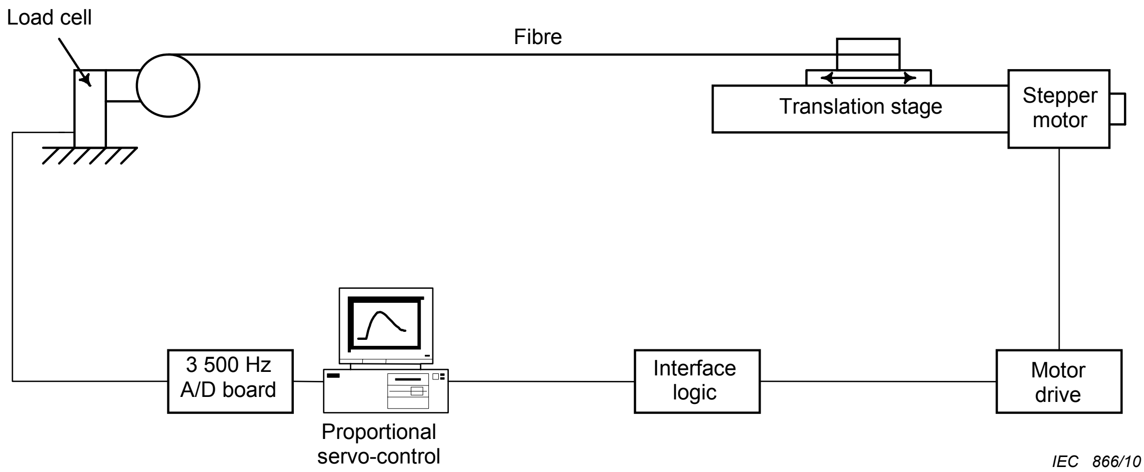


Figure C.1 – System to control stress rate

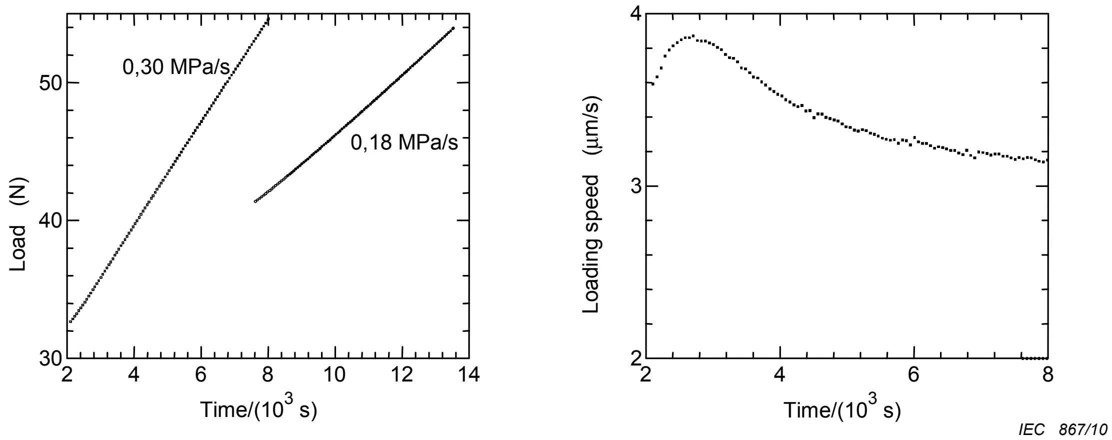


Figure C.2 – Time variation of load and loading speed

The Figure C.2 shows a comparison of the load profile and translation stage speed for experiments run at a constant speed of 2 mm/s and at a servoed constant stress loading rate of 0,3 MPa/s. That speed corresponds to a nominal stress rate of 0,29 MPa/s, yet the measured stress rate is only 0,18 MPa/s. In contrast, the servo-controlled result is a loading stress rate very close to the prescribed value. To achieve this, the loading speed was continuously varied as shown in the right hand figure.

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