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INTERNATIONAL STANDARD

Optical fibres –
Part 1-47: Measurement methods and test procedures – Macrobending loss

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FOREWORD

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International Standard IEC 60793-1-47 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This third edition cancels and replaces the second edition published in 2006. It constitutes a technical revision. The main change is listed below:

- Introduction of the Annex A describing small bend radius phenomena.

This standard is to be read in conjunction with IEC 60793-1-1.

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

CDV	Report on voting
86A/1207/CDV	86A/1240/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 IEC 60793 series, published under the general title *Optical fibres*, 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- withdrawn,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 publication may be issued at a later date.

INTRODUCTION

Publications in the IEC 60793-1 series concern measurement methods and test procedures as they apply to optical fibres.

Within the same series, several different areas are grouped, but all numbers are possibly not used, as follows:

– Parts 1-10 to 1-19: General
– Parts 1-20 to 1-29: Measurement methods and test procedures for dimensions
– Parts 1-30 to 1-39: Measurement methods and test procedures for mechanical characteristics
– Parts 1-40 to 1-49: Measurement methods and test procedures for transmission and optical characteristics
– Parts 1-50 to 1-59: Measurement methods and test procedures for environmental characteristics

OPTICAL FIBRES –

Part 1-47: Measurement methods and test procedures – Macrobending loss

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the macrobending loss of single-mode fibres (category B) at 1 550 nm or 1 625 nm, category A1 multimode fibres at 850 nm or 1 300 nm, and category A3 and A4 multimode fibres at 650 nm, 850 nm or 1 300 nm, thereby assisting in the inspection of fibres and cables for commercial purposes.

The standard gives two methods for measuring macrobending sensitivity:

- Method A – Fibre winding, pertains to category B single-mode fibres and category A1 multimode fibres.
- Method B – Quarter circle bends, pertains to category A3 and A4 multimode fibres.

For both of these methods, the optical power is measured using either the power monitoring or the cut-back technique.

Methods A and B are expected to produce different results if they are applied to the same fibre. This is because the key difference between the two methods is the deployment, including the bend radius and amount of fibre that is bent. The reason for the difference is that A3 and A4 multimode fibres are expected to be deployed in short lengths with relatively fewer bends compared to single-mode and category A1 multimode fibres.

In the following text, the “curvature radius” is defined as the radius of the suitable circular shaped support (e.g. mandrel or guiding groove on a flat surface) on which the fibre can be bent.

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 60793-1-1: *Optical fibres – Part 1-1: Measurement methods and test procedures – General and guidance*

IEC 60793-1-40: *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*

IEC 60793-1-46: *Optical fibres – Part 1-46: Measurement methods and test procedures – Monitoring of changes in optical transmittance*

IEC 61280-4-1: *Fibre-optic communication subsystem test procedures – Part 4-1: Cable plant and links – Multimode fibre-optic cable plant attenuation measurement*

3 Specimen

3.1 Specimen length

3.1.1 Method A – Fibre winding

The specimen shall be a known length of fibre, as specified in the detail specification. In particular, the length of the sample tested for loss is determined by the measurement set-up, i.e. curvature radius (R) and number of turns (N); any further fibre length does not affect the measurement results, provided that the signal to noise (S/N) ratio is optimised.

3.1.2 Method B – Quarter circle bends

The specimen length shall be determined according to the details shown in 5.2.

3.2 Specimen end face

Prepare a flat end face, orthogonal to the fibre axis, at the input and output ends of each test specimen.

4 Apparatus

4.1 Method A – Fibre winding

The apparatus consists of a tool (e.g. a mandrel or a guiding groove on a flat surface) able to hold the sample bent with a radius as stated in the specification (e.g. 30 mm for single-mode fibres and 37,5 mm for multimode fibres) and a loss-measurement instrument. Determine the macrobending loss at the wavelength as stated in the specification (e.g. 850 nm or 1 300 nm for multimode fibres, 1 550 nm or 1 625 nm for singlemode fibre) by using either the transmitted power monitoring technique (method A of IEC 60793-1-46) or the cut-back technique (method A of IEC 60793-1-40), taking care of the appropriate launch condition for the specific fibre type.

4.2 Method B – Quarter circle bends

The apparatus consists of one or more plates, each containing one or more "guide grooves," and a loss-measurement instrument. The plates shall be designed to be stacked during the test without contacting the sample fibre in a lower or higher plate; such contact will affect the measurement results. Each guide groove shall have a quarter circle segment (i.e. 90°) as shown in Figure 1. The bend radius r, i.e. the radius of the quarter circle segment, shall be stated in the detail specification. The width of each guide groove shall be at least 0,4 mm greater than the diameter of the fibre.

Determine the macrobending loss at the wavelength as stated in the specification (e.g. 650 nm, 850 nm, or 1 300 nm) by using either the transmitted power monitoring technique (method A of IEC 60793-1-46) or the cut-back technique (method A of IEC 60793-1-40), taking care of the appropriate launch condition for the specific fibre type.

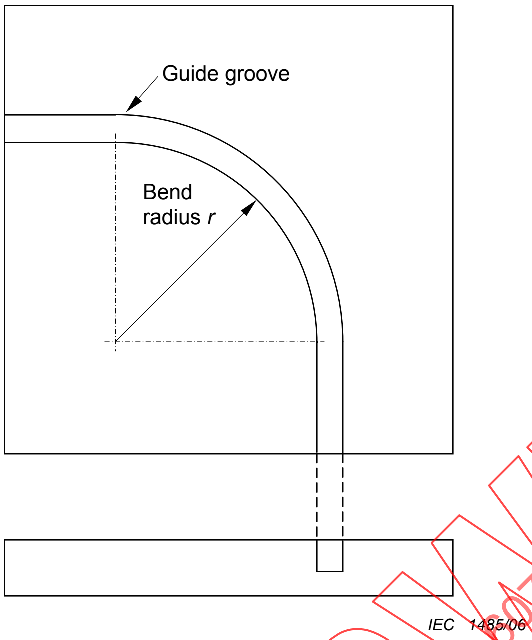

Figure 1 – Quarter circle guide groove in plate

5 Procedure

5.1 Method A – Fibre winding

5.1.1 General

Loosely wind the fibre on the tool, avoiding excessive fibre twist. The number of turns, curvature radius and wavelength at which loss is to be measured are discussed in the following paragraphs.

Since the actual curvature radius is critical, a maximum tolerance of ± 0,1 mm (for radii lower than or equal to 15 mm) or ± 0,5 mm to 1,0 mm (for larger radii) is accepted: a tighter tolerance on small radii is required for higher measurement sensitivity.

Both for single-mode and for multimode fibres, two optical powers can be measured using:

– the power-monitoring technique, which measures the fibre attenuation increase due to a change from the straight condition to a bent condition, or

– the cut-back technique, which measures the total attenuation of the fibre in the bent condition. In order to determine the induced attenuation due to macrobending, this value should be corrected for the intrinsic attenuation of the fibre.

The fibre length outside the mandrel and the reference cut-back length shall be free of bends that might introduce a significant change in the measurement result. Collection of excess fibre in a bend radius of at least 140 mm is recommended.

It is also possible to rewind the fibre from a mandrel with a large radius (introducing negligible macrobend loss) to the mandrel with the required radius. In this case, the macrobend loss can be determined directly by using the power-monitoring technique (without the correction for the intrinsic attenuation of the fibre).

Care must be taken in order not to introduce torsion on any fibre part during the measurements, as this would affect the result.

5.1.2 Single-mode fibres

Different applications may require different deployment conditions: fibre types have been developed which exhibit bending performances optimized for each condition.

Two typical environments are recognized for (possibly) different fibre types, for which different measurement set-ups should be considered when characterizing fibre performances.

a) Long distance networks: far from urban areas, space occupancy is not typically an issue, and bends imposed to the fibres can be limited to relatively large radii. Fibres designed for this application should be tested in similar conditions, i.e. with the samples wrapped around relatively large radius mandrels, e.g. in the range 25 mm to 30 mm.

   This measurement set-up is mainly affected by errors related to low S/N ratio and by unwanted tension, torsions or kinks on the relatively long fibre length used for the measurement.

b) Access networks: operating conditions require bending radii as small as possible, compatible with lifetime expectations and acceptable losses. Fibres designed for this application should be tested in similar conditions, i.e. with the samples bent at small radii, e.g. in the range 7,5 mm to 15 mm (see Annex A).

   The measurement can be affected by different sources, one of which is reflections. The reflection of light at the coating/air or coating/glass, at surrounding surfaces (including, when used, the mandrel surface), or at connectors are some examples.

The test can be carried out on samples either making complete (360 °) turn(s), in open air or around a suitable support (mandrel), or making an equivalent number of partial turns, for example u-turns (180 °) or quarter turns (90 °), in open air or around suitable supports. The length under test is different for complete and partial turns, for example the length of a complete turn being twice the length of a u-turn or four times the length of a quarter turn. In the following, the term "coil" refers to one complete turn. One coil could also be made of, for example two consecutive u-turns[1] or four consecutive quarter turns. This should be taken into account while normalizing the results to the length o the sample (number of coils).

The following recommendations apply to test conditions in both cases (items a) and b) above):

Number of turns

The number of turns should be in accordance with the values stated in the product specification.

For single-mode fibres, the attenuation increases in a linear fashion with the number of turns.

For each radius, the number of turns shall be chosen in such a way that:

– the induced loss is significantly higher than the detection limit of the set-up; when necessary, for example for low bend loss fibres, tests may be carried out with more turns than the specification requires – followed by linear normalization to the specified number;

– the induced loss is significantly lower than the onset of the non-linear region in the set-up; for bending radii in the range 5 mm to 10 mm this may imply that not more than 5 to 10 turns should be used.

Bend radius

1 If there is excessive displacement between successive u-turns, the length of the sample arranged on two u-turns can be shorter than one coil. A maximum displacement between adjacent u-turns of 0,5 mm is therefore suggested.

The value of bend radius shall be in accordance with the values stated in the product specification[2].

Wavelength

The measurement wavelength shall be 1 550 nm or 1 625 nm, in accordance with the relevant product specification; it should be considered that bending losses increase exponentially with the wavelength.

NOTE The homogeneity of bend loss in different angular positions over the cross section needs to be verified either by multiple angular position tests or by verifying the homogeneity of the effective refractive index profile establishing the guiding properties of the bent fibre under test

5.1.3 Multimode (A1) fibres

Macrobending loss in A1 multimode fibres varies with bend radius and number of turns around a mandrel, but is rather independent of the measuring wavelength, except for possible oscillating effects with wavelength, which are related to successive mode groups passing cut-off and having increased bend loss at these wavelengths.

The values of bend radius and number of turns shall be in accordance with the values stated in the specification. When testing multiple turns, the attenuation that occurs over a specific turn depends on the attenuation of the preceding turns. The incremental macrobending added loss decreases with each added turn. Macrobending added loss produced by multiple turns should not be expressed in the units of “dB/turn” by dividing the total added loss by the number of turns. Instead it must be reported in dB for the specified number of bends. An extrapolation to more than the specified number of turns will result in an overestimation of the overall loss.

For multimode fibres only, the launching characteristics of the light source at the launching position of the fibre being tested shall be consistent with the expected fibre application. Further details on MM launching conditions can be found in IEC 61280-4-1.

5.2 Method B – Quarter circle bends

The fibre to be tested should be carefully set in the guide groove(s). See Figure 1. The beginning of each controlled bend shall be s metres apart from the beginning of the next controlled bend. The beginning of the controlled bend closest to the launch end shall be 1 m from launch. The end of the controlled bend closest to the detector end shall be 1 m from the detector. See Figure 2.

The minimum specimen length shall be determined according to the following Equation (1):

$$L = (n-1) \times s + 2$$
$$s = \frac{3}{2}\pi \times R + 2 \times R \qquad (1)$$

where

L is the minimum sample length, (m)

n is the number of quarter-turn bends,

s is the interval between each bend, (m) and

R is the slack bend radius (m).

2 Bending loss on single-mode fibre increases exponentially as wavelength increases and as radius decreases (see Annex A).

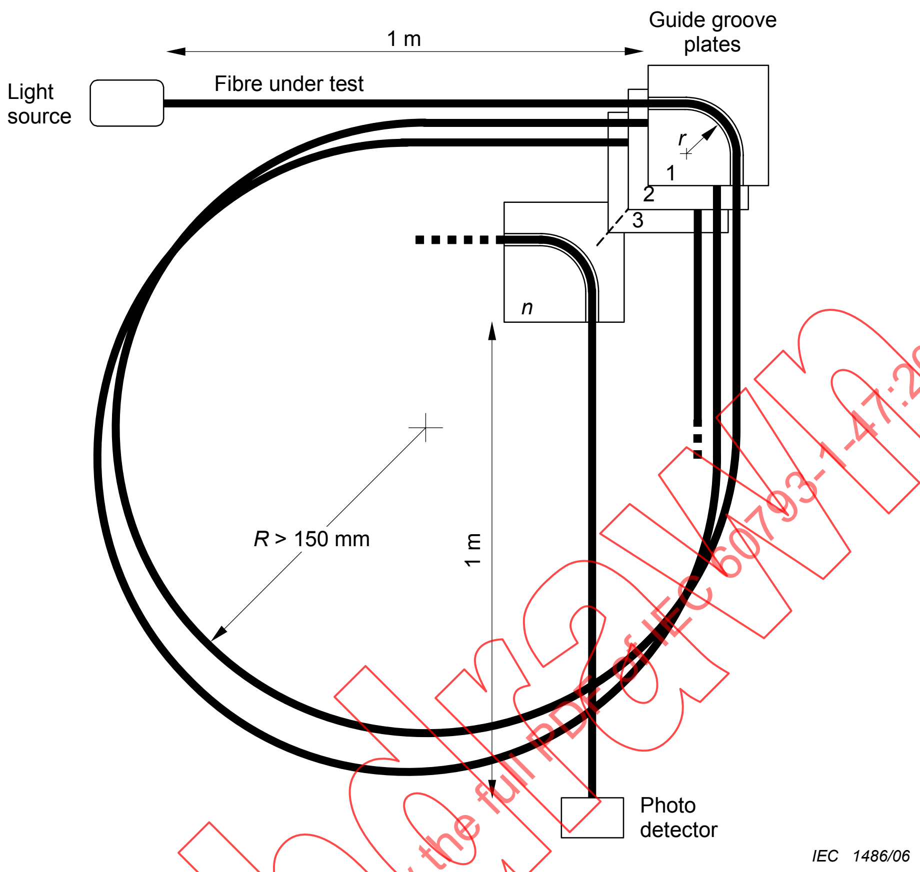

Figure 2 – Multiple bends using stacked plates

Macrobending loss caused by multiple bends of various radii can be measured simultaneously by stacking plates cut with grooves of various specified bend radii. See Figure 2.

Unless otherwise specified in the detail specification, the default values for the test are as follows:

- macrobend radius: r = 25 mm,
- number of macrobends: n = 10,
- slack bend radius, $R \geq$ 150 mm,
- wavelengths: 650 nm, 850 nm or 1 300 nm.

These parameters correspond to the interval between each macrobend being $s \geq$ 1 m, and a sample length $L \geq$ 11 m.

The added fibre loss caused by bending shall be measured using either the transmitted power monitoring technique (method A of IEC 60793-1-46) or the cut-back technique (method A of IEC 60793-1-40). Use cladding mode strippers at the source and detector ends of the specimen. A suitable cladding mode stripper consists of three turns of the fibre under test around a 15 mm radius mandrel.

Perform the test using the following procedure:

a) Cut the fibre to the appropriate length and wrap it on a spool or lay it on a flat surface so that the fibre has a bend radius ≥ 150 mm.

b) Measure the transmitted power.

c) Place the fibre in the measurement apparatus (Figures 1 and 2).

d) Measure the transmitted power.

NOTE When testing multiple macrobends, such as using the default value of n = 10, the mode distribution encountered at a specific macrobend may depend on how many macrobends precede it. For example, the first bend might influence the launch condition at the second bend, and the second bend might influence the launch condition at the third bend, etc. Consequently, the macrobending added loss at a given bend may be different than the macrobending added loss at another bend. In particular, the first bend may have the largest influence on following bends. Consequently, the macrobending added loss produced by multiple bends should not be expressed in the units of “dB/bend” (by dividing the total added loss by the number of bends). Therefore, the specification for macrobend added loss should not be stated in the units of “dB/bend.”

6 Calculations

The results are reported in dB as:

$$Loss(dB) = 10\log_{10}\left(\frac{P_{str}}{P_{Bend}}\right) \tag{2}$$

where P_{str} is the power measured without the bend and P_{Bend} is the power measured with the bend present[3].

NOTE For single-mode fibre, the loss can be reported in dB/turn.

7 Results

7.1 Information available with each measurement

Report the following information with each measurement:

– date and title of measurement;

– identification of specimen;

– length of specimen;

– curvature radius and measurement set-up (Method A);

– macrobend radius (Method B);

– number of turns (Method A);

– number of macrobends (Method B);

– wavelength(s) of interest;

– launching conditions (MM fibres only)

– macrobending loss (dB).

7.2 Information available upon request

The following information shall be available upon request:

– measurement method used: A or B ;

– power measurement method: power monitoring or cut-back;

– description of measurement apparatus arrangement;

– details of computation technique;

– date of latest calibration of equipment.

3 The power through the straight fibre can be calculated from the fibre attenuation coefficient, the length tested, and the output power of the source

8 Specification information

The detail specification shall specify the following information:

– type of fibre to be measured;
– launching conditions (MM fibres only)
– radius of curvature (Method A);
– macrobend radius (Method B);
– number of turns (Method A);
– number of macrobends (Method B);
– failure or acceptance criteria;
– information to be reported;
– wavelength(s) of interest;
– any deviations to the procedure that apply.

Annex A
(informative)

Small bend radius phenomena

A.1 General

This annex illustrates some features of single-mode fibre behaviour when bent to particularly small radii, depending on the fibre construction. It is based on practical experience of several fibre manufacturers.

The phenomena described in this annex might affect the quality of transmission. It is therefore recommended that fibre performances are confirmed under actual operating conditions, for example wavelength, bend radii and bent fibre length.

A.2 Interference between propagating and radiating modes

When measuring macrobending loss at low bend radii, a secondary effect due to interference among the fundamental propagating mode in the core and radiating modes can occur if the length of the sample under bend is not sufficient to suppress radiating modes. In this phenomenon, the propagating optical signal is irradiated from the bent fibre core and back reflected at curved interfaces outside the core (e.g. core-cladding or cladding-coating or coating-air, like in the so called whispering gallery modes phenomenon), thus interfering with the propagating mode. Under certain deployment conditions, constructive and destructive effects can occur leading to wavelength dependent losses at a certain bend radius.

In case these effects occur in the wavelength dependent loss, curve fitting can be applied for processing the spectral loss curve; the fit shall be based on the exponential behaviour of loss vs. wavelength. It is expected that the fitting will produce values that would be obtained with the interference effects substantially reduced, as would be the case if the test was carried out on a number of turns sufficiently large to suppress interference effects. The fitting technique however allows the measurement to be carried out and completed preventing the need of unpractical set-ups and measurement conditions.

An example of this oscillating behaviour and of a possible fitting curve (A) is shown in the following Figure A.1. Two consecutive deployments in a R = 7,5 mm test set-up with 18x a 180° bend (u-turns deployment) result in different loss curves but with coincident curve fits.

NOTE When fitting in the presence of peaks and valleys, verify that there are enough of them, for example four, so that their effect is balanced.

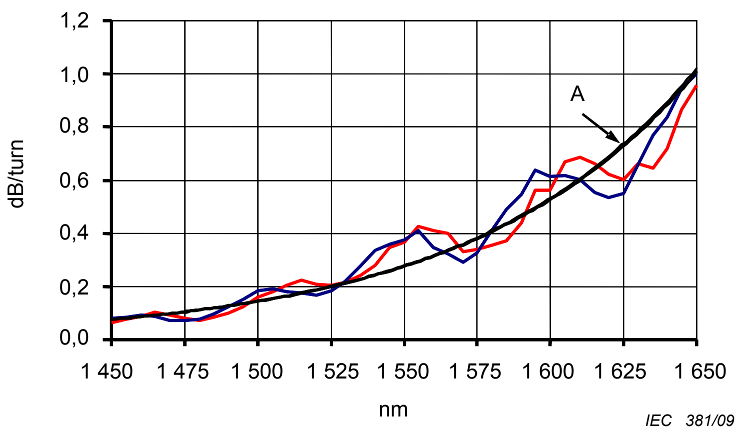

Figure A.1 – Loss curves versus curve fits