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Guidance of measurement methods and test procedures — Basic tests for polarization-maintaining optical fibres

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National foreword

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A list of organizations represented on this committee can be obtained on request to its secretary.

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GUIDANCE OF MEASUREMENT METHODS AND TEST PROCEDURES – BASIC TESTS FOR POLARIZATION-MAINTAINING OPTICAL FIBRES

FOREWORD

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC/TR 62349, which is a technical report, 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 2005. It constitutes a technical revision.

In this edition, guidance of measurement methods and test procedures for dimensional characteristics, cut-off wavelength, mode field diameter and beat length of polarization-maintaining optical fibres have been added. Thus, the title of the technical report is changed to "Guidance of measurement methods and test procedures – Basic tests for polarization-maintaining optical fibres" from "Guidance for polarization crosstalk measurement of optical fibre".

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86A/1488/DTR	86A/1507/RVC

Full information on the voting for the approval of this technical report 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.

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- withdrawn,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.

IMPORTANT – The “colour inside” logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

GUIDANCE OF MEASUREMENT METHODS AND TEST PROCEDURES – BASIC TESTS FOR POLARIZATION-MAINTAINING OPTICAL FIBRES

1 Scope and object

This technical report applies to polarization-maintaining (PM) optical fibres.

The object of this report is to define test procedures to be used in establishing uniform requirements for the geometrical and transmission properties of PM fibres.

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 60068-1, *Environmental testing – Part 1: General and guidance*

IEC 60793-1-20:2001, *Optical fibres – Part 1-20: Measurement methods and test procedures – Fibre geometry*

IEC 60793-1-44, *Optical fibres – Part 1-44: Measurement methods and test procedures – Cut-off wavelength*

IEC 60793-1-45:2001, *Optical fibres – Part 1-45: Measurement methods and test procedures – Mode field diameter*

IEC 60793-1-48, *Optical fibres – Part 1-48: Measurement methods and test procedures – Polarization mode dispersion*

3 Terms and definitions

For the purposes of this document, the following ters and definitions apply.

NOTE IEC 60793-1-1[1] [1] provides general definitions for testing.

3.1
polarization-maintaining optical fibre
PM fibre
optical fibre capable of transmitting, under external perturbations such as bending or lateral pressure, both independently of or either of the polarization modes HE^{X}_{11} and HE^{Y}_{11} whose directions of electric field vector intersect orthogonally with each other and which have different propagation constants

.

1 Numbers in square brackets refer to the bibliography.

3.2
phase beat length
one cycle of the periodical coupled polarization state by the phase difference of two linear-polarization modes intersecting orthogonally in the PM fibre

Note 1 to entry: Small beat length results in high polarization maintaining capability

3.3
group beat length
one cycle of the periodical coupled polarization state by the group delay difference of two linear-polarization modes intersecting orthogonally in the PM fibre

Note 1 to entry: Small beat length results in high polarization maintaining capability.

3.4
polarization crosstalk
strength of coupling of the two polarization modes intersecting orthogonally with each other within a polarization-maintaining optical fibre, representing the ratio in optical strength exiting the fibre of one polarization mode launched at the input end to the optical power of the other polarization mode exiting the fibre when only the former polarization mode is excited (see also 9.2.2.4.2)

4 Testing conditions

Unless otherwise specified, the test is conducted under the standard conditions specified in IEC 60068-1. However, when it is difficult to make measurements in the standard conditions, the test can be conducted in conditions other than the standard conditions provided that no doubts will arise about judgments.

5 Guidance for dimensional characteristics measurement of polarization-maintaining optical fibres

5.1 Object

Clause 5 describes measurement methods and test procedures for the dimensional characteristics of uncoated PM optical fibres.

5.2 Overview of method

This technical report gives measurement methods for dimensional characteristics of PM fibre which are given in terms of the following parameters:

- cladding diameter;
- cladding non-circularity;
- core concentricity error.

Two methods are described for measuring dimensional characteristics of PM fibre:

- Method A: Refracted near-field;
- Method B: Grey-scale technique of near-field light distribution.

Information pertaining to each individual method is given in Annexes A and C of IEC 60793-1-20:2001. Only notes for PM fibre are described below.

For a general optical fibre, a circle-fitting is used to determine the core centre. However, as for the PM fibre, in particular the elliptical core PM fibre, the core centre cannot be determined if an ellipse-fitting is not used, because the fibre has an oval core.

5.3 Reference test method

Method B is the reference test method (RTM), which is the one used to settle disputes.

6 Guidance for cut-off wavelength measurement of polarization-maintaining optical fibres

6.1 Object

Clause 6 describes a measurement method and a test procedure for the cut-off wavelength, λ_c of PM fibres.

6.2 Overview of method

The measurement method in this technical report describes procedures for determining the cut-off wavelength of a sample fibre in a short length, uncabled and primary coated condition (λ_c).

Information pertaining to each individual method is given in IEC 60793-1-44. Only notes for PM fibre are described below.

As shown in Annex A, the cut-off wavelength of the PM fibre is measured paying attention to excite a LP_{11} mode sufficiently and not to impose an extra, small bending more carefully than the cut-off wavelength measurement of a single-mode (SM) optical fibre.

The recommended deployment configuration of the sample fibre is as defined for the fibre cut-off wavelength in IEC 60793-1-44.

7 Guidance for mode field diameter measurement of polarization-maintaining optical fibres

7.1 Object

Clause 7 describes measurement methods and test procedures for the mode field diameter (MFD) of PM fibres.

7.2 Overview of method

Three methods are described for measuring the MFD of the PM fibre:

- Method A: direct far-field scan;
- Method B: variable aperture in the far field;
- Method C: near-field scan.

Information pertaining to each individual method is given in Annexes A, B and C of IEC 60793-1-45:2001. Only notes for PM fibre are described below.

The MFD of the PM fibre is non-axisymmetric in principle. The MFD is measured in the same directions by rotating the fibre around the axis properly. The azimuthal dependence of the MFD of a stress induced PM fibre and an elliptical sheath PM fibre are relatively small. On the other hand, the azimuthal dependence of the MFD of an elliptical core PM fibre is relatively large. The MFD of a stress induced fibre and an elliptical sheath PM fibre may be measured without rotating the fibre complying with the demand of a required accuracy of the customer depending on the measurement method.

In Method A, the MFD of a stress induced PM fibre and an elliptical sheath PM fibre may be measured without rotating the fibre complying with the demand of a required accuracy by the customer.

In Method B, the MFD of a stress induced PM fibre and an elliptical sheath PM fibre may be measured complying with the demand of a required accuracy of the customer. The MFD is measured as an axisymmetric electromagnetic field in Method B. Therefore, the MFD of the PM fibre cannot be measured in Method B. However, the MFD of a stress induced PM fibre and an elliptical sheath PM fibre may be measured in Method B because of the relatively small azimuthal dependence of the MFD. Method B cannot be used to measure the MFD of an elliptical core PM fibre.

In Method C, a two-dimensional detector is used. The fibre is rotated around the axis properly on measurement with a one dimensional detector.

8 Guidance for beat length measurement of polarization-maintaining optical fibres

8.1 Object

Clause 8 describes measurement methods and test procedures for the beat length of PM fibres.

8.2 Overview of methods

This technical report gives two methods for measuring the beat length of the PM fibre:

- Method A: Phase beat length measurement method (Direct measurement method);
- Method B: Group beat length measurement methods (Indirect measurement method).

Phase beat length, $L_{\mathrm{B\ (phase)}}$ and group beat length, $L_{\mathrm{B\ (group)}}$ are measured in Method A and B, respectively. As shown in Annex B, the beat lengths obtained by Methods A and B are based on different definitions, and will often give different results depending on the type of PM fibre. Differences of more than 100 % have been reported [2]. Therefore, the definition of the measured beat length parameter (phase or group) and the measurement method need to be stated in the measurement result of beat length. Mentioning of the measurement method may be excluded according to an agreement between the customer and the supplier.

8.3 Reference test method

Method A is the reference test method (RTM), which is the one used to settle disputes.

8.4 Specimen

A specimen length is the minimum necessary to set up the test apparatus. If the specimen is extra long, care shall be taken that no stresses will be induced in the specimen.

8.5 Beat length measuring method

8.5.1 Method A: Phase beat length measurement method

8.5.1.1 General

The phase beat length measurement method is based on applying a point-like perturbation along a short length of the fibre under test, and either monitor the changes in output power, or monitor changes in output SOP at one wavelength versus travel distance.

The perturbation can either be a lateral force or an electromagnet.

In this technical report, the test method using an electromagnet and the monitoring of output power versus travel distance is described in detail. Examples of other test methods expected to give similar measurement results are described e.g. in [3], [4] and [5].

8.5.1.2 Apparatus

a) General apparatus: See Figure 1 for a diagram of the test set-up.

An electromagnet is moved along the optical fibre longitudinal axis for Faraday rotation.

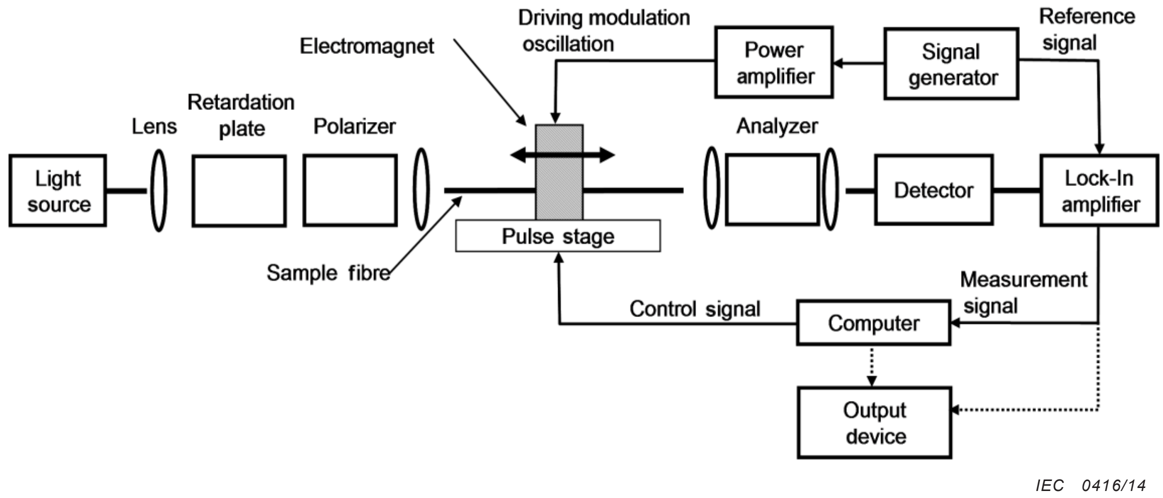

Figure 1 – Apparatus of beat length measurement – Method A

b) Light source

A light source, which has a narrow spectrum line-width, such as a DFB laser, is used.

c) Retardation plate

A retardation plate is provided to enable the input of certain level of optical power into the fibre even when the polarizer is rotated. The retardation plate converts the polarization of incident light from linear polarization into circular polarization.

d) Polarizer and analyser

A polarizer and an analyser are capable of outputting linearly polarized light having a certain direction of electric field vector when they have received light in a state of polarization.

e) Detector

A detector to be used is recommended to have a light receiving area that can detect all the optical power emitted from the output end of the optical fibre.

f) Electromagnet for Faraday rotation

An electromagnet for Faraday rotation rotates the polarization of the light in the fibre by applying an electromagnetical field along the fibre longitudinal axis. The polarization rotation is modulated by an electrical signal from outside to improve measurement sensitivity. See Annex C.

g) Pulse stage

A pulse stage needs to be able to move the electromagnet along the fibre longitudinal axis. The pulse stage has the moving range and pitch which are sufficient to measuring the beat length of the sample fibre.

h) Lock-in amplifier

A lock-in amplifier is used to improve measurement sensitivity. The lock-in amplifier has response time enough to respond the modulation speed of the electromagnet.

i) Signal generator

A signal generator provides modulated signal to the lock-in amplifier and the electromagnet.

j) Power amplifier

A power amplifier may be used as necessary. The power amplifier provides enough power for the electromagnet.

k) Computer

A computer controls the pulse stage and processes the output signal from the lock-in amplifier.

l) Output device

An output device is used to output a measurement profile processed by the computer. The output device may directly output the signal level of the lock-in amplifier for example on a plotter.

8.5.1.3 Procedure

a) Preparation and adjustment

Prepare a V-groove or bare fibre adapter to connect the sample fibre under test to the polarizer and analyser. Remove the primary coating from both ends of the fibre under test, and cleave the ends into mirror surfaces perpendicular to the axis of the fibre. Connect one end of the fibre to the polarizer using the V-groove. Connect the other end of the fibre to the analyser, and connect the analyser with the detector, so that all the input light can be received.

Rotate the polarizer and analyser to minimize the optical output power through the analyser. Next, adjust the analyser to maximize the output voltage of the lock-in amplifier.

b) Measurement

Move the electromagnet by driving the pulse stage. Memorize a relationship between the electromagnet travel distance Z and the lock-in amplifier output V. The relationship as shown in Figure 2 can be obtained. Measure N times the travel distance ΔZ_i which is a half period of the sequence of V.

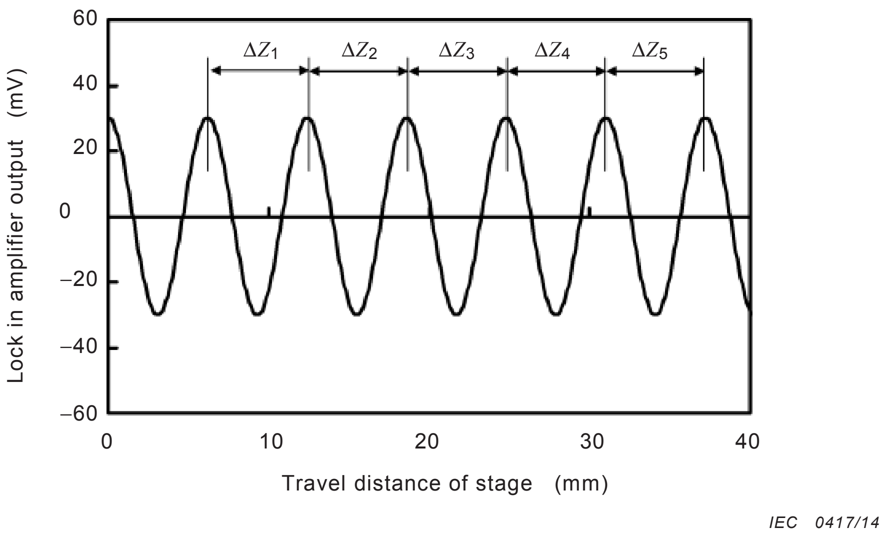

Figure 2 – Example of measurement profile by electro magnet

8.5.1.4 Calculation

The phase beat length $L_{B\ (phase)}$ is given by:

$$L_{B(phase)} = \frac{2\sum_{i=1}^{N} \Delta Z_i}{N} \quad (1)$$

where

$L_{B\ (phase)}$ is the phase beat length;

ΔZ_i is the travel distance of the stage where the lock-in amplifier output changes by the half period;

N is the number of the half period.

8.5.2 Method B: Group beat length measurement method

8.5.2.1 Apparatus and procedure

In this method, differential group delay (DGD) or group modal birefringence is utilized for calculation of beat length. It is measured by a method of polarization mode dispersion measurement (i.e. fixed analyser or wavelength scanning, stokes parameter evaluation, interferometry). Information pertaining to each individual method is given in IEC 60793-1-48.

8.5.2.2 Calculation

A group beat length can be calculated from results of the method of IEC 60793-1-48.

The group beat length $L_{B\ (group)}$ is given by

$$L_{B(group)} = \frac{\lambda}{B_{group}} \quad (2)$$

where

$L_{B\ (group)}$ is the group beat length;

B_{group} is the group modal birefringence in Method B;

λ is the wavelength.

The group modal birefringence B_{group} is given by

$$B_{group} = \frac{c}{L} \times \Delta\tau \quad (3)$$

where

c is the velocity of light in vacuum;

L is the fibre length;

$\Delta\tau$ is the differential group delay (DGD).

8.6 Results

8.6.1 Information available with each measurement

Report the following information on each measurement:

- date and title of measurement;
- length of specimen;
- identification of specimen;
- measurement wavelength;

- beat length;
- measurement method.

8.6.2 Information available upon request

The following information is available upon request:

- description of measurement apparatus arrangement;
- details of measurement apparatus;
- relative humidity and temperature of measurement;
- date of latest calibration of equipment;
- type of optical source used and its spectral width (FWHM) in the case of Method A.

9 Guidance for polarization crosstalk measurement of polarization-maintaining optical fibres

9.1 Object

Clause 9 describes two methods for measuring the polarization crosstalk of the PM fibre: the power ratio method (Method A) and the in-line method (Method B).

Polarization crosstalk occurs when there is imperfection in the isolation of two polarizations in a PM fibre.

9.2 Polarization crosstalk measuring method

9.2.1 General

Subclause 9.2 describes two methods for measuring the polarization crosstalk of PM fibres. Method A is the power ratio method, which uses the maximum and minimum values of output power at a specified wavelength, and Method B is the in-line method, which uses an analysis of the Poincaré sphere.

Details of each method are described in 9.2.2 and 9.2.3, respectively.

Crosstalk values obtained by Methods A and B are based on different definitions.

The crosstalk measured by Method A is defined as an 'averaged' value over a measured wavelength range. In contrast, the crosstalk value obtained from Method B shows 'the worst case' crosstalk value.

9.2.2 Method A: Power ratio method

9.2.2.1 Overview of the method

Method A is applicable to PM fibres, and connectors attached to one or both ends of the fibres, and to two or more such entities joined in series. Adjust the optical output to the minimum by rotating both the polarizer and analyser, and measure the optical output as P_{min}. Rotate the analyser 90°and measure the optical output as P_{max}.

Calculate the polarization crosstalk with the second set of values and take the average of the two values as the measured value.

9.2.2.2 Application

This measuring method is applied to the measurement of polarization crosstalk using the maximum and minimum values of optical output at a specified wavelength.

9.2.2.3 Test apparatus

Figure 3 shows an example of test apparatus.

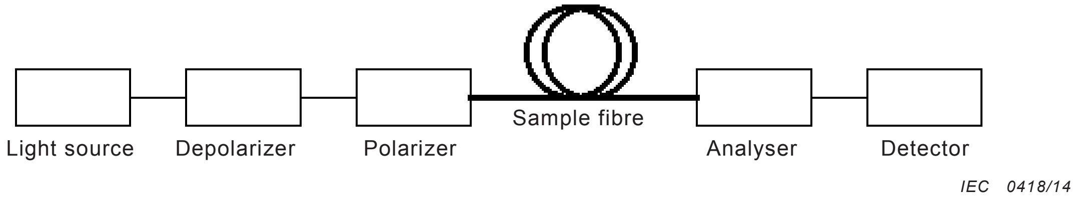

Figure 3 – Example of test apparatus for polarization crosstalk measurement (power ratio method)

a) Light source

The light source to be used is one with specified wavelength and wide spectrum bandwidth (20 nm or more at FWHM). A LED (light emitting diode) light source or a SLD (super-luminescent diode) light source is recommended for this test. The source power shall be kept below the level required to induce non-linear propagation effects; 10 mW is typically a safe limit. For a LED light source, whose power is low, however, a high-sensitivity detector shall be used.

b) Detector

The detector to be used has a light receiving area that can detect all the optical power emitted from the output end of the optical fibre. A power meter combining a photo-detector and an electronic processing system can also be used.

The detector response (including supplemental equipment such as a lock-in amplifier) shall be linear to within 5 % from the minimum to the maximum measured power and independent of the input polarization state.

c) Depolarizer

When the input light from the light source is polarized, a depolarizer is provided to enable the input of a certain level of optical power into the optical fibre even when the polarizer is rotated.

d) Polarizer and analyser

The polarizer is an optical device capable of outputting linearly polarized light having a certain direction of electric field vector when it has received light in a state of polarization. The polarizer to be used has an extinction ratio sufficient for measuring the polarization crosstalk of the optical fibre under test.

9.2.2.4 Test procedure

9.2.2.4.1 Preparation

Prepare a V-groove or bare fibre adapter to connect the polarizer, the analyser and the optical fibre under the test. Remove the primary coating from both ends of the known length of the optical fibre under the test, and cleave the ends into mirror surfaces perpendicular to the axis of the optical fibre. Connect the polarizer with one end of the optical fibre, using a V-groove or similar means. Connect the other end of the optical fibre to the analyser, and connect the analyser to the detector, so that all the output light can be received.

Set the fibres on a V-groove or similar device, taking care that no stresses will be induced in the optical fibre, especially in the cladding. For example, when fixing the optical fibre with a V-groove, place soft cloth, such as gauze, between the optical fibre and the cladding holder so that the cladding holder may not cause any stress directly to the cladding. Also, the bare fibre adapter, when used, is a type that does not cause stresses in the sheath of the optical fibre core.

9.2.2.4.2 Measurement and calculation

Adjust the optical output to the minimum by rotating both the polarizer and analyser and record the optical output as P_{min1}. Rotate only the analyser 90°and record the optical output as P_{max1}. Rotate only the polarizer 90°, and record the optical output as P_{min2}. Then rotate only the analyser 90°and record the optical output as P_{max2}.

Two sets of the polarization crosstalk are derived from the measurement.

$$CT_1 = 10\ \log(P_{min1}/P_{max1})\ \ (\text{dB}) \quad (4)$$

$$CT_2 = 10\ \log(P_{min2}/P_{max2})\ \ (\text{dB}) \quad (5)$$

The polarization crosstalk CT_A is given by:

$$CT_A = (CT_1+CT_2)/2 \quad (6)$$

9.2.3 Method B: In-line polarimetric method

9.2.3.1 General

Method B is applicable to single sections of PM fibre, to cascaded PM fibres, and to PM fibres interconnected with optical devices. It is also applicable to polarization-maintaining components that lack PM fibre pigtails, in which case the measurement is performed on a PM fibre jumper connected to the output of the component. The method requires gently stretching or heating approximately 0,1 m to 0,3 m of PM fibre in order to generate at least a fraction of a cycle of phase shift between the fast and slow waves.

9.2.3.2 Limitations of the method

The optical source shall be spectrally narrow (e.g., DFB laser or tunable laser source).

The crosstalk at any point in a concatenation of PM fibres and/or components is the instantaneous result of the temperatures and mechanical stresses acting at all upstream elements. Thus, in order to obtain a 'worst case' local crosstalk value, it is necessary to sufficiently perturb the upstream path. This is simple for concatenations of a few elements but is more time-consuming for paths that contain a large number of PM fibre and/or component interfaces.

9.2.3.3 Measurement process

The fibre is gently stretched or heated in the region in which the crosstalk is to be measured. This stimulus produces an arc on the unit radius Poincaré sphere, as shown in Figure 4.

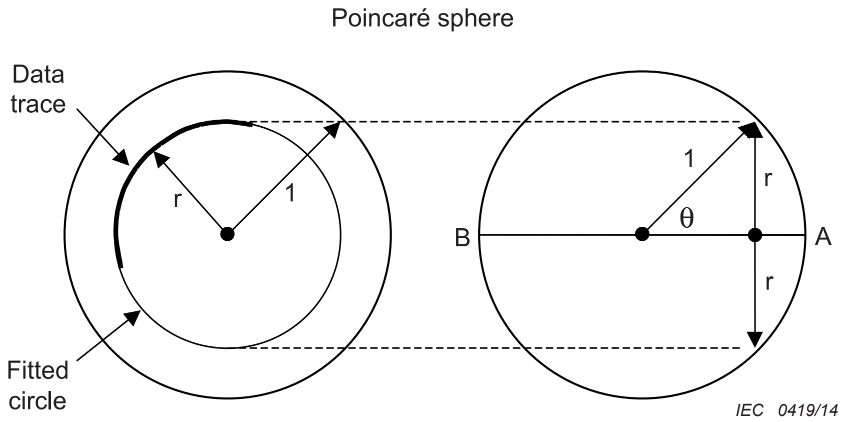

Figure 4a – Front view of data arc and fitted circle

Figure 4b – 90° – Rotated cutaway view defining the geometrical relationships

Figure 4 – Poincaré sphere representations for Method B

Points A and B represent the polarization modes (eigenmodes) of the fibre.

A circle is fitted to the arc and the radius *r* of the circle is recorded. The crosstalk value CT_B is calculated from the radius according to

$$CT_B = 10\log\frac{1-\sqrt{1-r^2}}{1+\sqrt{1-r^2}} \tag{7}$$

9.2.3.4 Mathematical basis

The following derivation pertains to the Poincaré sphere representations shown in Figure 4. The ratio of power in the output principal states is given by

$$\frac{P_B}{P_A} = \frac{1-\cos\theta}{1+\cos\theta} \tag{8}$$

The radius of the circle is related to θ by

$$\theta = \sin^{-1}(r) \tag{9}$$

Therefore:

$$\cos\theta = \sqrt{1-r^2} \tag{10}$$

The crosstalk value is given by

$$CT_B = 10\log\frac{1-\sqrt{1-r^2}}{1+\sqrt{1-r^2}} \tag{11}$$

Alternatively, in terms of the angular length of the arc, crosstalk is given by

$$CT_B = 10\log\frac{1-\cos\theta}{1+\cos\theta} \tag{12}$$

Annex A
(informative)

Cut-off wavelength of PM fibre and SM fibre – Profiles and bend dependence of cut-off wavelength

A refractive index of a core of a PM fibre varies according to the polarization mode. Also the cut-off wavelength varies according to the polarization mode.

The cut-off wavelength profile of te PM fibre and the SM fibre are shown in Figure A.1. Due to a separation of the LP_{11} mode, the cut-off wavelength profile of the PM fibre typically has two peaks of LP_{11} mode and the cut-off wavelength profile results are broader than that of the SM fibre.

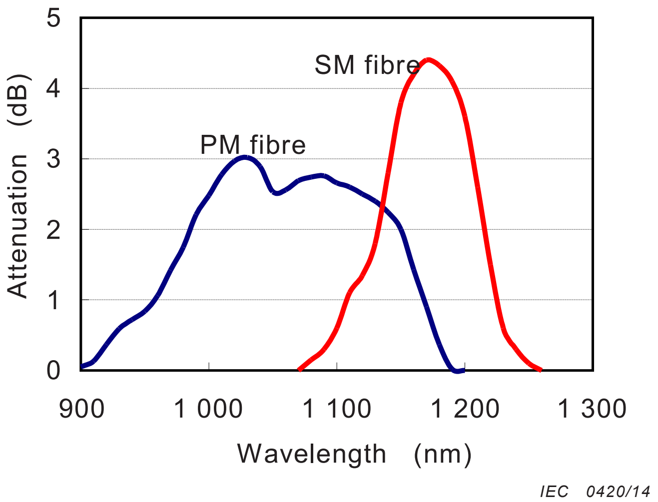

Figure A. 1 – Cut-off wavelength profiles of PM fibre and SM fibre

Figure A.2 shows the cut-off wavelength profile of the same PM fibre as Figure A.1 when there are some extra bends on the measured fibre. The peak in the longer wavelength disappears and the measured cut-off wavelength results in a smaller value.

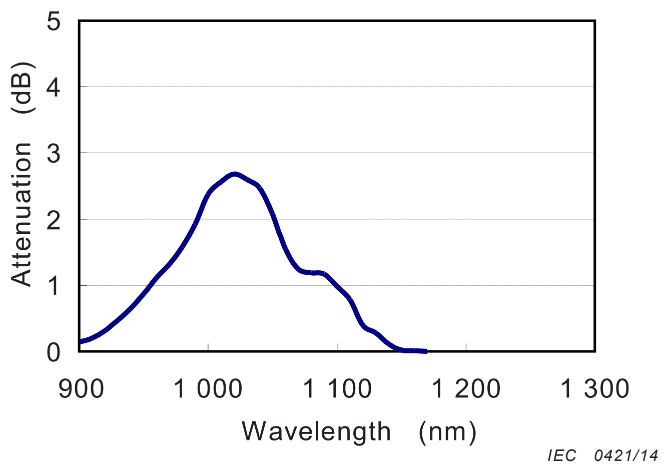

Figure A. 2 – Cut-off wavelength profile of PM fibre with extra bending

Due to a separation of the LP_{11} mode, even if a maximum attenuation of LP_{11} mode is equal to or greater than 2 dB as defined in IEC 60793-1-44, it is possible that the longer wavelength side of LP_{11} mode is not sufficiently excited. The longer wavelength side of the LP_{11} mode of the PM fibre is sensitive to the bending relative to that of SM fibre. Therefore, measurement requires special attention not to impose an extra small bending.

It is not enough to take care only of a maximum attenuation of the LP_{11} mode for the cut-off wavelength measurement of the PM fibre. The LP_{11} mode separation is varied by a refractive index difference between the x- and y-axis by birefringence such as stress induced fibre or core non-circularity such as elliptical core fibre. If the cut-off wavelength profile is separated into two peaks, the higher cut-off is the reported one.

Annex B
(informative)

Difference of beat length by measurement method

B.1 Modal birefringence and beat length

The refractive index difference of two orthogonally polarized modes of a PM fibre results from the core shape and the stress distribution. The difference is the phase modal birefringence and is given by:

$$B_{\text{phase}} = n_{\text{x}} - n_{\text{y}} \tag{B.1}$$

where

B_{phase} is the modal birefringence;

n_x, n_y are the refractive indices of two orthogonally polarized modes.

The phase difference $\Delta\phi$ between the two polarized modes results from the birefringence of the optical fibre when two orthogonally polarized modes propagate through the fibre which has a length of L.

$$\Delta\phi = \frac{2\pi \times B_{\text{phase}}}{\lambda} L \tag{B.2}$$

where

$\Delta\phi$ is the phase difference between two polarized modes;

B_{phase} is the phase modal birefringence;

L is the fibre length;

λ is the wavelength.

The phase difference changes the state of polarization of the fibre periodically along its longitudinal direction. The beat length is a length in which the phase difference becomes 2π, and is defined by:

$$L_{B(\text{phase})} = \frac{\lambda}{B_{\text{phase}}} \tag{B.3}$$

where

$L_{B(\text{phase})}$ is the phase beat length;

λ is the wavelength;

B_{phase} is the phase modal birefringence.

Method A measures the beat length directly.

B.2 Beat length defined by Method B

In principle, Method B measures the polarization mode dispersion. A modal birefringence and a beat length measured by Method B, which are defined on the bases of differential group refractive index, are different from a model birefringence and a beat length measured on the bases of the definition of Equations (B.1) and (B.3).

A modal birefringence measured by Method B is calculated from the wavelength dependence of the phase difference. The phase difference is expressed as

$$\Delta\phi = -2\pi \times B_{\text{phase}} \times L \times \frac{\Delta\lambda}{\lambda^2} + \frac{2\pi \times L}{\lambda}\frac{dB_{\text{phase}}}{d\lambda}\Delta\lambda \qquad \text{(B.4)}$$

where

$\Delta\phi$ is the phase difference between two polarized modes;

B_{phase} is the phase modal birefringence in Method A;

L is the fibre length;

λ is the wavelength;

$\Delta\lambda$ is the wavelength shift.

Assume that the wavelength dependence of the modal birefringence is relatively small, the second term in Equation (B.4) is negligible. The group modal birefringence B_{group} is defined by

$$\Delta\phi = -2\pi \times B_{\text{group}} \times L \times \frac{\Delta\lambda}{\lambda^2} \qquad \text{(B.5)}$$

where

$\Delta\phi$ is the phase difference between two polarized modes;

B_{group} is the modal birefringence in Method B;

L is the fibre length;

λ is the wavelength;

$\Delta\lambda$ is the wavelength shift.

The group modal birefringence B_{group} is calculated by

$$B_{\text{group}} = \frac{\lambda^2}{L \times \Delta\lambda_{p-p}} \qquad \text{(B.6)}$$

where

B_{group} is the group modal birefringence in Method B;

L is the fibre length;

λ is the wavelength;

$\Delta\lambda_{p-p}$ is the wavelength shift which corresponds to $\Delta\phi = 2\pi$.

The beat length measured in Method *B*, $L_{B(\text{group})}$ is defined by substituting B_{group} in Equation (B.3).

$$L_{B(\text{group})} = \frac{\lambda}{B_{\text{group}}} \qquad \text{(B.7)}$$

where

$L_{B(\text{group})}$ is the group beat length measured in Method B;

λ is the wavelength;

B_{group} is the group modal birefringence in Method B.

The beat lengths defined by Equations (B.3) and (B.7) are different by the difference between B_{phase} and B_{group}. According to Equations (B.4) and (B.5), the relationship between B_{phase} and B_{group} is defined by:

$$B_{\text{group}} = B_{\text{phase}} - \lambda \times \frac{dB_{\text{phase}}}{d\lambda} \qquad \text{(B.8)}$$

where

B_{group} is the group modal birefringence in Method B;

B_{phase} is the phase modal birefringence in Method A;

λ is the wavelength.

Care shall be taken that B_{group} and $L_{B(\text{group})}$ shift from B_{phase} and $L_{B(\text{phase})}$ by the wavelength dispersion of B_{phase}.

Annex C
(informative)

Electromagnet for Faraday rotation

An example of the electromagnet for Faraday rotation used in Method A for beat length measurement is shown in Figure C.1. The brass tube is inserted in the coil. The brass tube has a through hole for inserting an optical fibre and 1 mm air gap. The brass tube has the air gap to apply the optical fibre to magnetic field.

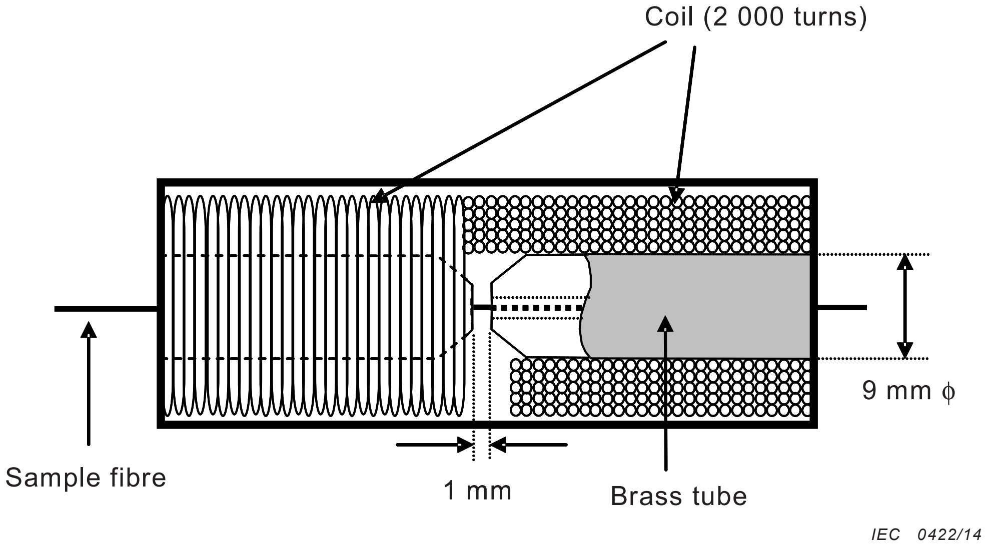

Figure C. 1 – A schematic of the electromagnet

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