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colour inside

Optical fibres –
Part 1-45: Measurement methods and test procedures – Mode field diameter

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FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 60793-1-45 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.

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

a) improvement of the description of measurement details for B6 fibre;

b) correction of Equations (1), (2),(5) and (6);

c) correction of Table E.1, Table E.2 and Table E.3.

The text of this International Standard is based on the following documents:

CDV	Report on voting
86A/1758/CDV	86A/1802/RVC

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the 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 document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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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, 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 1-45: Measurement methods and test procedures – Mode field diameter

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the mode field diameter (MFD) of single-mode optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60793-1-40:2001, *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*

IEC 60793-2~~:1998~~, *Optical fibres – Part 2: Product specifications – General*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 General consideration about mode field diameter

The mode field diameter measurement represents a measure of the transverse extent of the electromagnetic field intensity of the guided mode in a fibre cross section, and it is defined from the far-field intensity distribution as a ratio of integrals known as the Petermann II definition. See Equation (1).

The definitions of mode field diameter are strictly related to the measurement configurations. The mathematical equivalence of these definitions results from transform relationships between measurement results obtained by different implementations summarized in Figure 1 as follows.

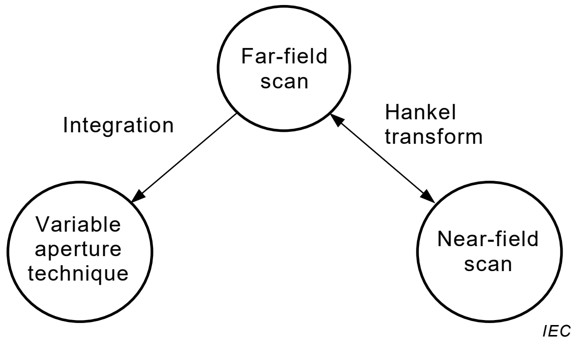

Figure 1 – Transform relationships between measurement results

Four methods are described for measuring mode field diameter:

– method A: direct far-field scan;
– method B: variable aperture in the far field;
– method C: near-field scan;
– method D: bi-directional backscatter using an optical time domain reflectometer (OTDR).

All four methods apply to all categories of type B single-mode fibre shown in IEC 60793-2 and operating near 1 310 nm or 1 550 nm. Method D is not recommended for the measurement of fibres of unknown type or design.

Information common to all four methods is contained in Clauses 1 to 11, and information pertaining to each individual method appears in annexes A, B, C and D, respectively.

5 Reference test method

Method A, direct far-field scan, is the reference test method (RTM), which shall be the one used to settle disputes.

6 Apparatus

6.1 General

The following apparatus is common to all measurement methods. Annexes A, B, C and D include layout drawings and other equipment requirements for each of the four methods, respectively.

6.2 Light source

For methods A, B and C, use a suitable coherent or non-coherent light source, such as a semiconductor laser or a sufficiently powerful filtered white light source. The source shall produce sufficient radiation at the intended wavelength(s) and be stable in intensity over a time period sufficient to perform the measurement.

A monochromator or interference filter(s) may be used, if required, for wavelength selection. The detail specification shall specify the wavelength of the source. The full width half maximum (FWHM) spectral line width of the source shall be less than or equal to 10 nm, unless otherwise specified.

See Annex D for method D.

6.3 Input optics

For method A, B, and C, an optical lens system or fibre pigtail may be employed to excite the specimen. It is recommended that the power coupled into the specimen be relatively insensitive to the position of its input end face. This can be accomplished by using a launch beam that spatially and angularly overfills the input end face.

If using a butt splice, employ index-matching material between the fibre pigtail and the specimen to avoid interference effects. The coupling shall be stable for the duration of the measurement.

See Annex D for method D.

6.4 Input positioner

Provide means of positioning the input end of the specimen to the light source. Examples include the use of x-y-z micropositioner stages, or mechanical coupling devices such as connectors, vacuum splices, three-rod splices. The position of the fibre shall remain stable over the duration of the measurement.

6.5 Cladding mode stripper

Use a device that extracts cladding modes. Under some circumstances, the fibre coating will perform this function.

6.6 High-order mode filter

Use a means to remove high-order propagating modes in the wavelength range that is greater than or equal to the cut-off wavelength of the specimen. For example, a one-turn bend with a radius of 30 mm on the fibre is generally sufficient for most B1.1 to B6 fibres. For some B6 fibres, smaller radius, multiple bends or longer specimen length can be applied to remove high-order propagating modes.

6.7 Output positioner

Provide a suitable means for aligning the fibre output end face in order to allow an accurate axial adjustment of the output end, such that, at the measurement wavelength, the scan pattern is suitably focused on the plane of the scanning detector. Such coupling may include the use of lenses, or may be a mechanical connector to a detector pigtail.

Provide means such as a side-viewing microscope or camera with a crosshair to locate the fibre at a fixed distance from the apertures or detectors. It may be sufficient to provide only longitudinal adjustment if the fibre is constrained in the lateral plane by a device such as a vacuum chuck (this depends mainly upon the size of the light detector).

6.8 Output optics

See the appropriate annex: A, B, C or D.

6.9 Detector

See the appropriate annex: A, B, C or D.

6.10 Computer

Use a computer to perform operations such as controlling the apparatus, taking intensity measurements, and processing the data to obtain the final results. For individual details, see the appropriate annex: A, B, C or D.

7 Sampling and specimens

7.1 Specimen length

For methods A, B and C, the specimen shall be a known length, typically 2 m ± 0,2 m ~~of single-mode~~ for most B1.1 to B6 fibres. For some B6 fibres, longer specimen length can be used to avoid high-order propagating modes, 22 m for example.

~~NOTE~~ For method D, OTDR, the sample ~~must~~ shall be long enough to exceed (or be positioned beyond) the dead zone of the OTDR, with both ends accessible, as described in the backscatter test method IEC 60793-1-40.

7.2 Specimen end face

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

8 Procedure

See Annexes A, B, C and D for methods A, B, C and D, respectively.

9 Calculations

9.1 Basic equations

The basic equations for calculating mode field diameter by methods A, B and C are given below. For additional calculations, see the appropriate annex: A, B, C or D. Sample data sets for methods A, B and C are included in Annex E.

9.2 Method A – Direct far-field scan

The following equation defines the mode field diameter for method A in terms of the electromagnetic field emitted from the end of the specimen.

Calculate the mode field diameter by scanning the far-field data and evaluating the Petermann II integral, which is defined from the far-field intensity distribution:

~~$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\frac{\int_0^{\pi/2} P_F(\theta)\sin(\theta)\cos(\theta)d\theta}{\int_0^{\pi/2} P_F(\theta)\sin^3(\theta)\cos(\theta)d\theta}\right]$$~~

$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\frac{\int_0^{\pi/2} P_F(\theta)\sin(\theta)\cos(\theta)d\theta}{\int_0^{\pi/2} P_F(\theta)\sin^3(\theta)\cos(\theta)d\theta}\right]^{1/2} \quad (1)$$

where

$2W_0$ is the mode field diameter in µm;

$P_F(\theta)$ is the far-field intensity distribution;

λ is the wavelength of measurement in µm;

θ is the angle in the far-field measurement from the axis of the fibre.

NOTE 1 The integration limits are shown to be from zero to $\pi/2$, but it is understood that the integrands approach zero with increasing argument so that, in practice, the integrals can be truncated.

NOTE 2 P_F is $F^2(\theta)$ in ITU-T documents.

The far-field method for obtaining the mode field diameter of a single-mode fibre is a two-step procedure. First, measure the far-field radiation pattern of the fibre. Second, use a mathematical procedure based on the Petermann II far-field definition to calculate the mode field from far-field data, as described in Equation (1) above.

Annex E provides sample data and calculated $2W_0$ values for ~~$2W_0$ to enable one to check~~ verifying the numerical evaluation of the Petermann II Integral. The sample data are in the form of the folded power, $P_F(\theta)$, as a function of the angle, θ.

9.3 Method B – Variable aperture in the far field

The following equations define the mode field diameter for method B in terms of the electromagnetic field emitted from the end of the specimen.

Calculate the mode field diameter, $2W_0$, as follows:

~~$$2W_0 = \left(\frac{\lambda}{\pi D}\right)\left[\int_0^\infty a(x)\frac{x}{\left(x^2+D^2\right)^2}\,dx\right]^{1/2}$$~~

$$2W_0 = \left(\frac{\lambda}{\pi D}\right)\left[\int_0^\infty a(x)\frac{x}{\left(x^2+D^2\right)^2}\,dx\right]^{-1/2} \quad (2)$$

where

$2W_0$ is the mode field diameter, in µm;

λ is the wavelength of measurement, in µm;

D is the distance between the aperture and the fibre, in mm;

$a(x)$ is the complementary aperture transmission function, calculated as

$$a(x) = 1 - \frac{P(x)}{P(\max)} \quad (3)$$

where

$P(x)$ is the power measured through an aperture of radius, x, or half angle, θ;

$P(\max)$ is the maximum power, assuming an infinite aperture;

x is the aperture radius, calculated as

$$x = D\tan(\theta) \quad (4)$$

~~where D is the distance between the aperture and the fibre, in mm.~~

~~The mathematical equivalence of equations (1) and (2) is valid in the approximation of small angles, θ. Under this approximation, equation (2) can be derived from equation (1) by integration.~~

Another equivalent expression of Equation (2) is

~~$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\int_0^\infty a(\theta)\sin 2\theta\,d\theta\right]^{1/2}$$~~

$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\int_0^\infty a(\theta)\sin 2\theta\,d\theta\right]^{-1/2} \quad (5)$$

~~where~~

~~$2W_0$ is the MFD, in µm;~~

~~$a(\theta)$ is the complementary aperture function, calculated as~~

~~$$a(\theta) = 1 - \frac{P(\theta)}{P(\max)} \quad (6)$$~~