IEC 60793-1-43

Edition 2.0 2015-03

INTERNATIONAL STANDARD

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inside

Optical fibres – Part 1-43: Measurement methods and test procedures – Numerical aperture Measurement

Fibres optiques – Partie 1-43: Méthodes de mesure et procédures d'essai – Mesure de l'ouverture numérique

IEC 60793-1-43:2015-03(en-fr)

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FOREWORD

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International Standard IEC 60793-1-43 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This bilingual version (2019-09) corresponds to the monolingual English version, published in 2015-03.

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

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

- expansion of the scope to include A1, A2, A3 and A4 multimode fibre categories;
- addition of measurement parameters of sample length and threshold values, product specific to the variables that are now found in the product specifications;

- a new Annex B entitled "Product specific default values for NA measurement";
- addition of a new Technique 4 for measuring NA of A4d fibres;
- a new Annex A entitled "Mapping NA measurement to alternative lengths" that gives a mapping function to correlate shorter sample length measurements to the length suggested in the reference test method Na_{ff}.

This International Standard is to be used in conjunction with IEC 60793-1-1, IEC 60793-1-21 and IEC 60793-1-22.

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

CDV	Report on voting
86A/1566/CDV	86A/1622/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.

The French version of this standard has not been voted upon.

This publication 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 publication will remain unchanged until the stability date indicated on the IEC website 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- withdrawn,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.

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OPTICAL FIBRES –

Part 1-43: Measurement methods and test procedures– Numerical aperture measurement

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the numerical aperture of optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

The numerical aperture (NA) of categories A1, A2, A3 and A4 multimode fibre is an important parameter that describes a fibre's light-gathering ability. It is used to predict launching efficiency, joint loss at splices, and micro/macrobending performance.

The numerical aperture is defined by measuring the far-field pattern (NA_{ff}). In some cases the theoretical numerical aperture (NA_{th}) is used in the literature, which can be determined from measuring the difference in refractive indexes between the core and cladding. Ideally these two methods should produce the same value.

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

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

IEC 60793-1-22, *Optical fibres – Part 1-22: Measurement methods and test procedures – Length measurement*

IEC 60793-2-10, *Optical fibres – Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres*

IEC 60793-2-20, *Optical fibres – Part 2-20: Product specifications – Sectional specification for category A2 multimode fibres*

IEC 60793-2-30, *Optical fibres – Part 2-30: Product specifications – Sectional specification for category A3 multimode fibres*

IEC 60793-2-40, *Optical fibres – Part 2-40: Product specifications – Sectional specification for category A4 multimode fibres*

3 Overview of method

This test procedure describes a method for measuring the angular radiant intensity (far-field) distribution from an optical fibre. The numerical aperture of multimode optical fibre can be calculated from the results of this measurement using Equation (10) for NA in the far-field, NA_{ff}, as described in 8.3.

As background the maximum theoretical NA of a multimode fibre is defined as follows:

$$NA_{th} = \sin \theta_m \qquad (1)$$

where

NA_{th} is the maximum theoretical numerical aperture;

θ_m is the largest incident meridional ray angle that will be guided by the fibre.

In terms of the fibre index profile:

$$NA_{th} = \sqrt{n_1^2 - n_2^2} \qquad (2)$$

where n_1 is the maximum refractive index of the core, and n_2 is the average refractive index of the cladding far from the core region. Figure 1 below shows a refractive index profile of a graded index multimode fibre and indicates n_1 and n_2.

Figure 1 – Representative refractive index profile for a graded index multimode fibre

NA_{ff} can be determined from a far-field radiation pattern measurement on a short length of fibre or from a measurement of a fibre's refractive index profile. Using the far-field method, the intensity pattern, $I(\theta)$, of a fibre is acquired, and the NA_{ff} (numerical aperture in the far-field) is defined as the sine of the half-angle where the intensity has decreased to a threshold percentage (k_{NA} %) of its maximum value. The threshold used depends on the type of multimode fibre being measured and are given in the detailed product specification for the fibre being measured.

4 Reference test method

The reference test method (RTM) for measuring numerical aperture is the far-field measurement defined in this standard.

NOTE The core and cladding indexes can be empirically determined by Method A (refractive near-field measurement) of IEC 60793-1-20 to approximate the theoretical NA (NA_{th}).

5 Apparatus

5.1 Input system

5.1.1 Light source

Use an incoherent light source capable of producing an area of substantially constant radiance (variations of less than 10 % in intensity) on the endface of the specimen. It shall be stable in intensity and position over a time interval sufficient to perform the measurement.

Class A fibres' core geometry shall be determined by employing an illuminator at the operating wavelength of the fibre that satisfies the following spatial and angular requirements.

The power per unit area in the focal plane of the fibre under test shall not vary more than ±10 % across the core area.

The power per unit solid angle shall not vary more than ±10 % across the core's acceptance cone.

5.1.2 Input optics

Use a system of optical components to create a substantially constant radiance spot larger in diameter than the endface of the specimen and with a numerical aperture greater than that of the specimen. The light source shall be incoherent but with a spectral width < 100 nm, full-width half-maximum.

The NA_{ff} is impacted by the measurement wavelength. For this reason, the centre wavelength is given as part of the detailed product specifications including IEC 60793-2-10, IEC 60793-2-20, IEC 60793-2-30 and IEC 60793-2-40. Default values for the centre wavelength are also listed in Annex B. Provide a means of verifying the alignment of the endface. Optical filters may be used to limit the spectral width of the source.

5.1.3 Fibre input end support and alignment

Provide a means of supporting the input end of the specimen to allow stable and repeatable positioning without introducing significant fibre deformation. Provide suitable means to align the input endface with respect to the launch radiation.

5.1.4 Cladding mode stripper

Provide means to remove cladding light from the specimen. Often the fibre coating is sufficient to perform this function. Otherwise, it will be necessary to use cladding mode strippers near both ends of the test specimen. Note that some detailed product specifications require longer specimen lengths to help remove cladding modes as well.

5.2 Output system and detection

5.2.1 General

Four equivalent techniques may be used to detect the angular radiant intensity (far-field) distribution from the specimen. Techniques 1 and 2 are angular scans of the far-field pattern. Technique 3 is a scan of the spatial transform of the angular intensity pattern. (A small or large area scanning detector may be used.) Technique 4 uses an inverse far-field measurement.

5.2.2 Technique 1 – Angular scan (see Figure 2)

5.2.2.1 Fibre output end support and alignment

Use a means of supporting and aligning the output end of the specimen that allows alignment of the endface coincident with the axis of rotation of the optical detector and coincident with the plane of rotation of the optical detector.

For example, a vacuum chuck mounted on X-Y-Z micropositioners, with a microscope fixture for aligning the fibre end would be suitable. Examples include a goniometer or stepper-motor driven rotational stage.

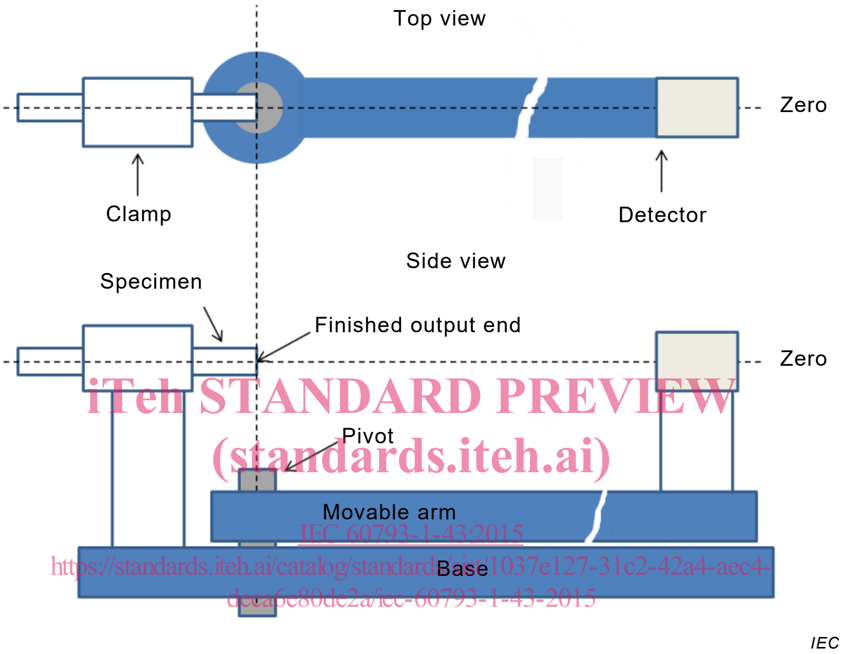

Figure 2 – Technique 1 – Angular scan

5.2.2.2 Detection system mechanics

Use a suitable means for rotation of the optical detector that allows the detector to scan an arc sufficient to cover essentially the full radiation cone from the specimen (for example, a calibrated goniometer). The axis of rotation of the mechanism shall intercept the endface of the specimen and shall be perpendicular to the specimen axis, and the rotation plane of this mechanism shall be coincident with specimen axis. Provide means for recording the relative angular position of the detector with respect to the specimen output axis.

Use a detector that is linear within 5 % over the range of intensity encountered. A pinhole aperture may be used to restrict the effective size of the detector in order to achieve increased resolution. The detector or aperture size can be determined according to the angular resolution that is desired for the apparatus according to Equation (3):

$$D = 4\,R\,\sin(\delta) \tag{3}$$

where

D is the detector aperture diameter, in mm;

δ is the desired angular resolution, in degrees (°);

R is the distance from the specimen output endface to the detector or aperture, in mm;

A is the resolution of ± 0,5° that is typically used. R shall also meet the far-field requirement:

$$R \geq \frac{d^2}{\lambda} \tag{4}$$

where

R is the distance from the sample output endface to the detector or aperture, in mm;

d is the diameter of the emitting region of the specimen, in μm;

λ is the centre wavelength of the optical source, in nm.

5.2.2.3 Recording

The detection angle is recorded directly using this technique.

5.2.3 Technique 2 – Angular scan (see Figure 3)

Use a means of supporting the specimen such that the output endface is coincident with the axis of rotation of the specimen. This mechanism (e.g. a goniometer or precision rotating stage) shall rotate sufficiently to allow the full radiation cone in the plane of rotation to sweep past the fixed detector. That is, the rotation shall be greater than the total angle of the specimen output radiation.

The detector requirements are the same as Technique 1 and like Technique 1 the angle is recorded as a direct result of this method. Provide means to record the included angle formed by the specimen axis and the imaginary line between the detector and the specimen endface.

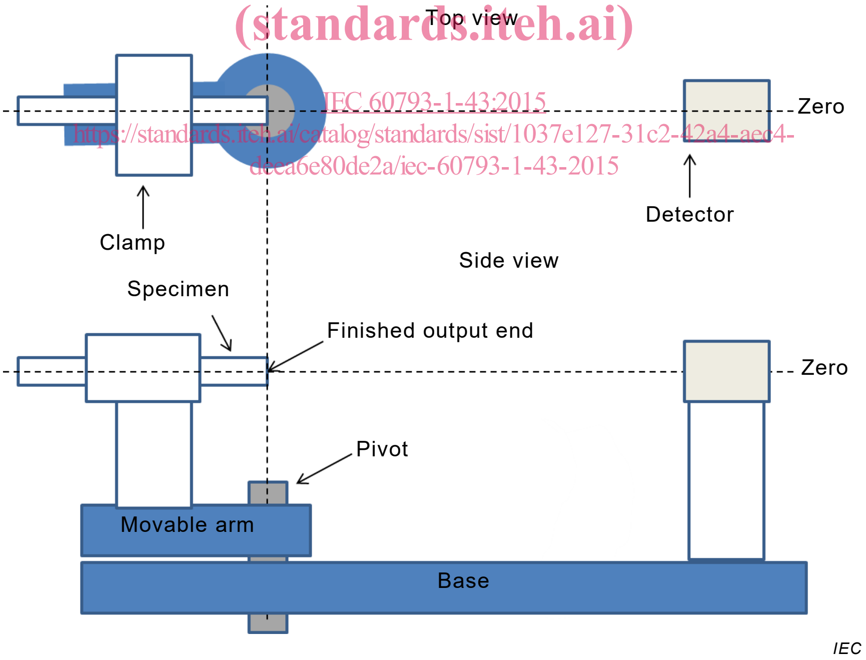

Figure 3 –Technique 2 – Angular scan

5.2.4 Technique 3 – Scan of the spatial field pattern (see Figure 4)

5.2.4.1 Fibre output end support apparatus

Provide a means of supporting and aligning the specimen output end that allows stable and repeatable positioning.

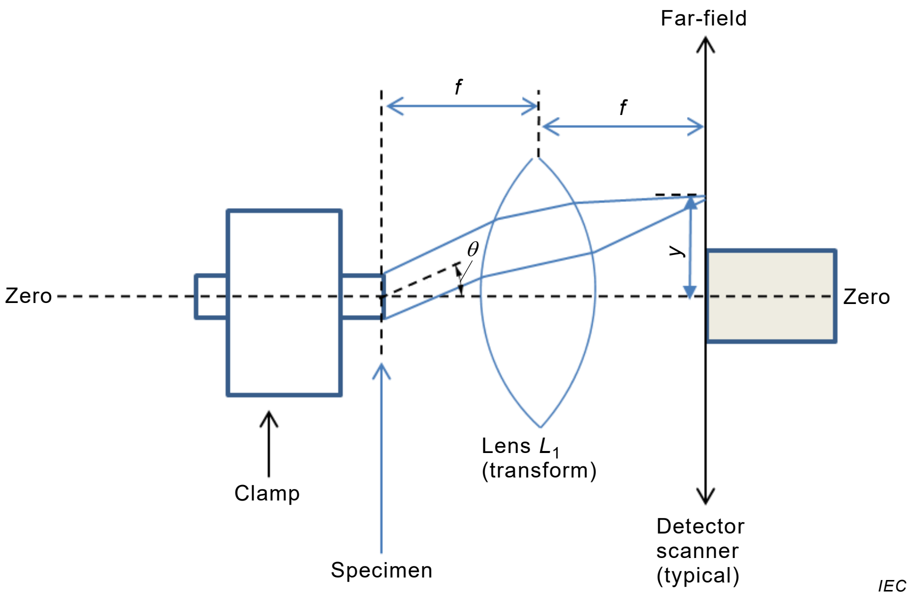

Figure 4 – Technique 3 – Scan of the spatial field pattern

5.2.4.2 Far-field transformation and projection

Create a spatial representation of the far-field of the specimen by suitable means (for example, by using a microscope objective or other well corrected lens to obtain the Fourier transform of the fibre output near-field pattern).

Scan this pattern or its image using a pinhole aperture so as to enable the far-field intensity to be recorded. The size of the pinhole aperture shall be less than, or equal to, one-half the diffraction limit of the system:

$$d \leq \frac{1{,}22\, M \lambda f}{2D} \qquad (5)$$

where

d is the diameter of the pinhole, in µm;

M is the magnification from the back focal plane of the transforming lens to the scanning plane;

λ is the spectral wavelength emitted from the fibre, in nm;

f is the focal length of the transform lens, in mm;

D is the fibre core diameter, in mm.

The numerical aperture of the lens, L_1, should be large enough so as not to limit the numerical aperture of the fibre specimen.

5.2.4.3 Scanning system

Provide a method of scanning the far-field pattern with respect to the pinhole aperture and detector.

5.2.4.4 System calibration

Perform a calibration to measure the distance of movement of the scanning system in the back focal plane of the far-field transforming lens to the emission angle, θ, with respect to the specimen output end axis as shown in Equation (6). Inputting a set of known angles and recording the output positions can be used for this purpose.