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Fibre optic interconnecting devices and passive components – Basic test and measurement procedures –
Part 3-43: Examinations and measurements – Mode transfer function measurement for fibre optic sources

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International Standard IEC 61300-3-43 has been prepared by subcommittee 86B: Fibre optic interconnecting devices and passive components, of IEC technical committee 86: Fibre optics.

This standard cancels and replaces IEC/PAS 61300-3-43, published in 2006. This first edition constitutes a technical revision.

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

FDIS	Report on voting
86B/2780/FDIS	86B/2810/RVD

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.

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

FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – BASIC TEST AND MEASUREMENT PROCEDURES –

Part 3-43: Examinations and measurements – Mode transfer function measurement for fibre optic sources

1 Scope

This part of IEC 61300 describes the method for measuring the mode transfer function (MTF) to be used in characterising the launch conditions for measurements of attenuation and or return loss of multimode passive components. The MTF may be measured at the operational wavelengths.

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 61300-1, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 1: General and guidance*

IEC 61300-3-4, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-4: Examination and measurements – Attenuation*

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

3 General description

The modal distribution launched into multimode fibre can vary widely with different light sources. This variation in launched modal distribution can result in significant differences in measured attenuation in the same component. The MTF test method gives information about the launched modal distribution (LMD) condition in a measured component. The MTF test method is based on a measurement of the near-field intensity distribution in the fibre [1], [2][1].

4 Theory

For a fibre with a power-law index profile $n(r)$, given by,

$$n(r) = n_1 \left[1 - 2\Delta \left(\frac{r}{a} \right)^{\alpha} \right]^{0,5} \quad \left(\frac{r}{a} \right) \leq 1 \tag{1}$$

where

a is the fibre core radius;

α is the profile factor (α = 2 for a parabolic profile);

[1] Figures in square brackets refer to the Bibliography.

Δ is the relative index difference, given by

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \quad (2)$$

where

n_1 is the index at fibre centre;

n_2 is the cladding index.

The near-field intensity profile in the fibre $I(r)$ may be determined from an integration of the mode transfer function $MTF(\delta)$ in the fibre, as follows (ignoring constants):

$$I(r) = \int_{\Delta(r/a)^{\alpha}}^{\Delta} MTF(\delta) \times d\delta \quad (3)$$

where

δ is the normalised propagation constant;

r/a is the normalised radial position.

Differentiating both sides gives the MTF as follows (ignoring constants):

$$MTF(\delta) = \left[\frac{dI(r)}{dr} \times \frac{1}{r^{\alpha-1}}\right]_{\delta=\Delta(r/a)^{\alpha}} \quad (4)$$

The MTF is usually plotted as in terms of the principal mode number m divided by the maximum principal mode number M, where

$$\frac{m}{M} = \left[\frac{\delta}{\Delta}\right]^{(2+\alpha)/2\alpha} = \left[\frac{r}{a}\right]^{(2+\alpha)/2} \quad (5)$$

The term (m/M) is usually referred to as the relative mode number, or the normalised mode number.

The maximum principle mode number M, is given by

$$M = \sqrt{\frac{\alpha}{\alpha+2}}\left(\frac{n_1 2\pi a}{\lambda}\right)\sqrt{\Delta} \quad (6)$$

A typical normalised MTF plot is shown in Figure 1, where it can be seen, in this example, that normalised mode numbers up to about 0,6 are equally filled and higher order modes are progressively less well-filled.

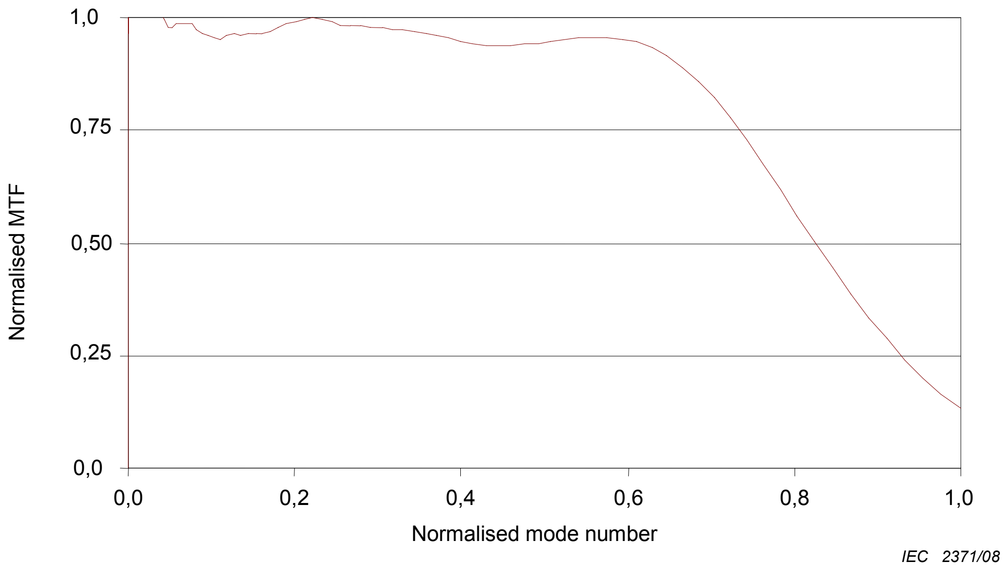

Figure 1 – Example of normalised MTF

4.1 Alternative method

If the profile factor, α, in Equation (4) is not known, then an alternative expression for MTF can be used.

It is known[3] that in a fully-filled fibre (i.e. MTF=1 for all mode numbers) the near-field intensity profile, I_o, is approximately the same shape as the square of the refractive index profile, $n(r)^2$. Furthermore, the term $r^{\alpha-1}$ Equation (4) is equal (ignoring constants) to the differential of $n(r)^2$ and so Equation(4) can be rewritten as:

$$MTF(\delta) = \left[\frac{dI(r)}{dr} \times \frac{1}{dI_o(r)/dr} \right]_{\delta = \Delta \left(r/a \right)^2} \qquad (7)$$

where a value of α=2 has been assumed in order to compute values for the normalised mode number.

Thus the MTF is equal to the ratio of the derivative of the intensity profile under test to the derivative of the intensity profile of the same fibre under fully-filled conditions.

4.2 Mode power distribution

For graded index multimode fibre the number of discrete modes in a particular mode group is proportional to the principal mode number. Thus higher-order mode groups contain more modes and therefore will carry more light if all the modes are equally excited. This can be represented by the mode power distribution (MPD), defined as:

$$MPD(m) = MTF(m) \times m \qquad (8)$$

Because of this relationship of modes within mode groups, the MPD transform effectively displays the relative power in the mode groups.

An example of a normalised MPD is shown in Figure 2, where it can be seen, in this case, that the peak power level occurs around 0,65 normalised mode number.

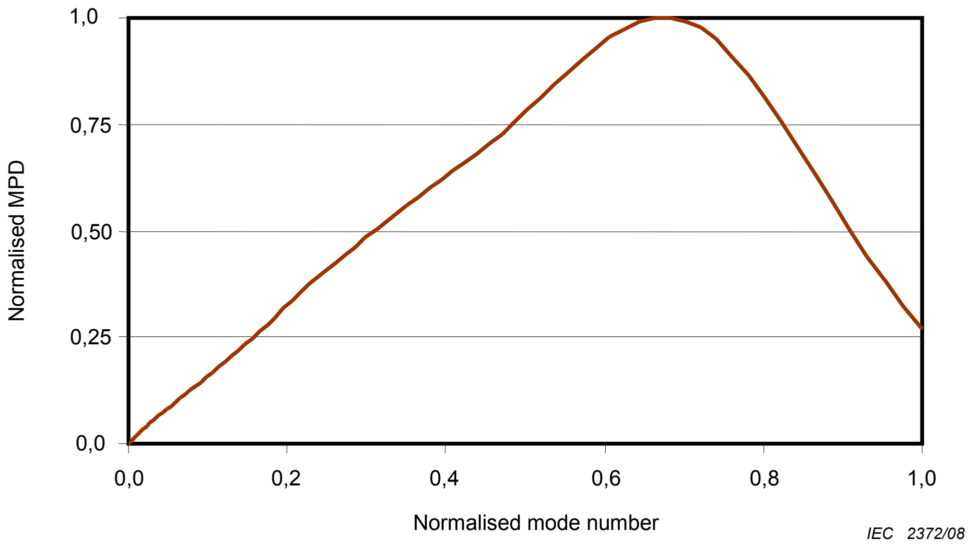

Figure 2 – Example of normalised MPD

4.3 Constraints

The MTF measurement method described herein is only valid under certain conditions, as follows:

- modes within a mode group carry the same power;
- there are random phases between the propagating modes.

It has been found[4] that both these conditions can be simultaneously met if the line-width $\Delta\lambda$ of the source is sufficiently broad, leading to the so-called "mode-continuum approximation", given by:

$$\frac{\Delta\lambda}{\lambda} \geq \frac{\sqrt{2\Delta}}{a \times k_0 \times N} \qquad (10)$$

where

λ is the optical wavelength;

k_0 = $2\pi/\lambda$;

N is the group index, given by

$$N = n_1 - \lambda \times \frac{dn_1}{d\lambda} \qquad (11)$$

Typically, for a 50 µm core diameter fibre, with 0,21 numerical aperture, then $\Delta\lambda$ > 0,5 nm at 850 nm and $\Delta\lambda$ > 1,0 nm at 1 300 nm satisfy this condition.

If the source line-width does not meet this criterion then interference between propagating modes may take place, resulting in "speckle" in the near-field image. The method can, however, still be applied to such sources by gently shaking, or somehow agitating, the fibre under test so as to cause a temporal averaging of the speckle pattern. In this case, it is important to ensure the near-field is azimuthally symmetric. This can be achieved by checking that the MTFs measured at 45° intervals around the fibre coincide with each other[5].

- The peak of the MPD occurs at a normalised mode number of <0,8.

It is known that deviation of the measured near-field intensity profile $I(r)$ from the power law profile in Equation (1), for fibres that are well-filled, may occur towards the core/cladding boundary. It is recommended that, in this case, the alternative method for the determination of MTF described in 4.1 is employed.

5 Apparatus

5.1 General

The apparatus is essentially a video microscope where a near-field image of the end of the fibre under test is formed on the surface of a camera by an optical system. The camera image is then digitised by a video digitiser and transferred to a computer for analysis and data presentation.

A schematic of a typical measurement configuration is shown in Figure 3.

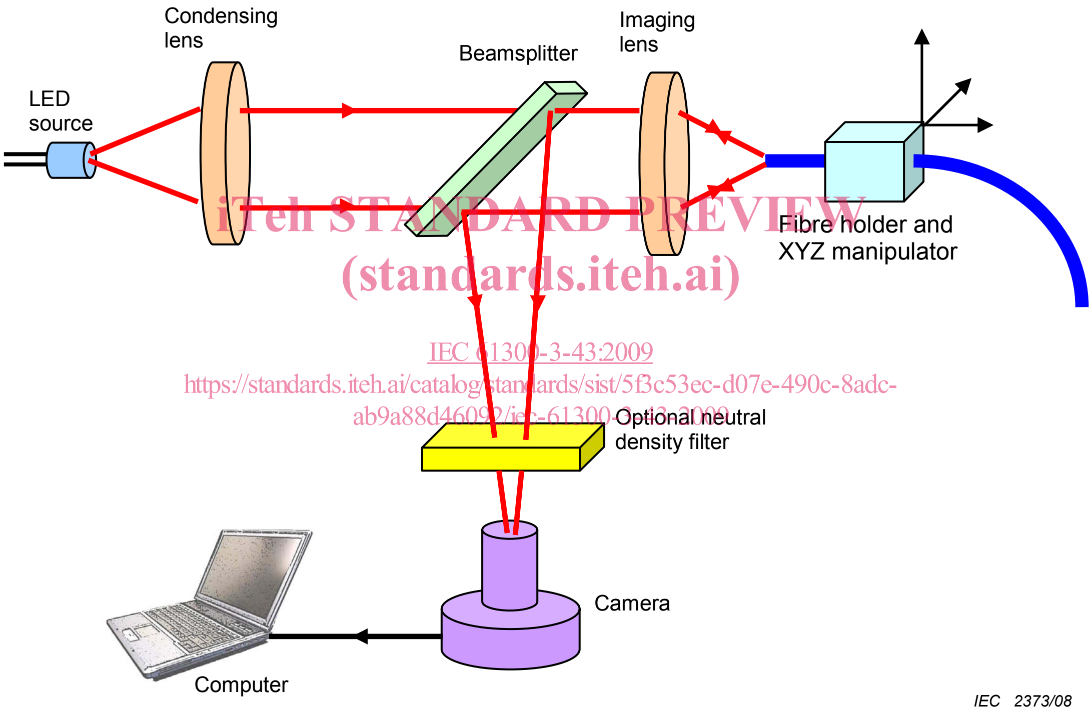

Figure 3 – Schematic of measurement apparatus

5.2 Test sample

The test sample consists of a multimode patch cord attached to a light source. It should be recognised that the mode distribution at the output of the patch cord is a product of both the launch conditions of the source and of the patch cord itself. The resultant MTF is therefore not a parameter of either the light source or the patch cord individually but rather of the combination, including the particular conditions under which the patch cord is disposed, such as bend radius.

5.3 Sample positioning device

A positioning device is required to ensure that the end of the patch cord under test is located on the optical axis of the instrument and also in the correct axial position to give a well-focussed image on the camera. For this purpose, an XYZ manipulation stage may be used or, preferably, a suitable connector receptacle mounted axially with the optics. An example is a standard 2,5 mm ferrule receptacle which is able to accommodate several connector types,