INTERNATIONAL STANDARD

IEC 61745

First edition
1998-08

End-face image analysis procedure for the calibration of optical fibre geometry test sets

Reference number
IEC 61745:1998(E)

Numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series.

Consolidated publications

Consolidated versions of some IEC publications including amendments are available. For example, edition numbers 1.0, 1.1 and 1.2 refer, respectively, to the base publication, the base publication incorporating amendment 1 and the base publication incorporating amendments 1 and 2.

Validity of this publication

The technical content of IEC publications is kept under constant review by the IEC, thus ensuring that the content reflects current technology.

Information relating to the date of the reconfirmation of the publication is available in the IEC catalogue.

Information on the subjects under consideration and work in progress undertaken by the technical committee which has prepared this publication, as well as the list of publications issued, is to be found at the following IEC sources:

- **IEC web site***
- **Catalogue of IEC publications**
  Published yearly with regular updates
  (On-line catalogue)*
- **IEC Bulletin**
  Available both at the IEC web site* and as a printed periodical

Terminology, graphical and letter symbols

For general terminology, readers are referred to IEC 60050: *International Electrotechnical Vocabulary* (IEV).

For graphical symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to publications IEC 60027: *Letter symbols to be used in electrical technology*, IEC 60417: *Graphical symbols for use on equipment. Index, survey and compilation of the single sheets* and IEC 60617: *Graphical symbols for diagrams*.

* See web site address on title page.

INTERNATIONAL STANDARD

IEC 61745

First edition
1998-08

End-face image analysis procedure for the calibration of optical fibre geometry test sets

International Electrotechnical Commission 3, rue de Varembé Geneva, Switzerland
Telefax: +41 22 919 0300 e-mail: inmail@iec.ch IEC web site http: //www.iec.ch

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE V

For price, see current catalogue

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

END-FACE IMAGE ANALYSIS PROCEDURE FOR THE CALIBRATION OF OPTICAL FIBRE GEOMETRY TEST SETS

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.
3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical reports or guides and they are accepted by the National Committees in that sense.
4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.
5) The IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.
6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61745 has been prepared by IEC technical committee 86: Fibre optics.

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

FDIS	Report on voting
86/125/FDIS	86/134/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.

Annex C forms an integral part of this standard.

Annexes A, B, D, E, F and G are for information only.

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

END-FACE IMAGE ANALYSIS PROCEDURE FOR THE CALIBRATION OF OPTICAL FIBRE GEOMETRY TEST SETS

1 General

1.1 Scope and object

In the research and production environments there exists a range of test methods for characterizing the geometry of optical fibres. Furthermore, each test method may determine one or more of the many parameters required for complete geometrical characterization. This International Standard describes the calibration of test sets which perform end-face image analysis, also known as near-field or grey-scale analysis. The principles, however, may be applied to test sets of a different type.

This standard addresses the calibration of measurements made on single-mode fibres only; however, this type of test set may also be used to measure the geometrical parameters of the cores of multimode fibres, but the evaluation of uncertainties associated with these measurements is beyond the scope of this standard.

The procedures outlined are to be performed by calibration laboratories and by the manufacturers or users of geometry test sets, for the purpose of calibrating geometry test sets and for evaluating the uncertainties in measurements made on calibrated test sets. The calibration of fibre coating or cable measurement test sets is not covered by this standard. The object of this standard is to define a standard procedure for the calibration of test sets for measuring the glass geometry of optical fibres.

1.2 Definitions

For the purpose of this International Standard, the following definitions apply.

1.2.1
accredited calibration laboratory
calibration laboratory authorised by the appropriate National Standards laboratory to issue calibration certificates with a specified uncertainty, which demonstrate traceability to national standards

1.2.2
artefact
any object that is measured on or used to calibrate a geometry test set. An artefact may be, for example, an optical fibre or a chromium-on-glass pattern

1.2.3
calibration
process by which the relationship between the values indicated by the geometry test set under calibration and the known values of the calibration standard is established. The purpose of calibration is to bring all geometry test sets into substantial agreement with a national standards laboratory. This may be performed either by adjustment of the geometry test set or by documentation of a calibration factor(s) in a calibration certificate. The pertaining environment and instrument conditions at the time of calibration are usually recorded. Calibration includes estimation of all uncertainties.

1.2.4
calibration chain
chain of transfers from a national standard to the geometry test set through intermediate or working standards (see figure 1)

1.2.5
calibration checking
establishing that a geometry test set that has been previously calibrated but has reached its calibration due date remains within specified uncertainty limits. If the geometry test set has drifted outside these limits, then re-calibration is required. Otherwise, the re-checking period can be extended for a stated period. The test set may be checked using a working standard

1.2.6
calibration standard
artefact that is calibrated against a reference standard and is used to calibrate test sets. The artefact may be a fibre or a chromium-on-glass pattern. Proper use of a calibration standard ensures traceability. The term includes the reference standard, the transfer standard and the working standard(s), in descending order of metrological uncertainty

1.2.7
combined standard uncertainty
combination of a number of individual standard uncertainties.

The term "accuracy" should be avoided in this context.

In calibration reports and technical data sheets, the combined standard uncertainty in the geometry test set measurement is reported as an overall expanded uncertainty with the applicable confidence level, for example 95,5% or 99,7%.

1.2.8
confidence level
estimation of the probability that the true value of a measured parameter lies within a given range (expanded uncertainty)

1.2.9
correction offset
number that is added to or subtracted from the measurement result of a test set to correct for a known physical effect

1.2.10
coverage factor, *k*
factor used to calculate the expanded uncertainty *U* from the standard uncertainty

1.2.11
expanded uncertainty, *U*
range of values within which the true value of the measured parameter, at the stated confidence level, can be expected to lie. It is also called the confidence interval and is equal to the coverage factor *k* times the standard uncertainty *u:*

$$U = k \cdot u$$

The measurement uncertainty of a geometry test set should be specified in the form of expanded uncertainty.

NOTE – When the distribution of uncertainties is assumed to be normal and a large number of measurements are made, then confidence levels of 68,3 %, 95,5 % and 99,7 % correspond to values for *k* of 1, 2, and 3 respectively (see clause C.3).

1.2.12
geometry test set
instrument used to measure the geometrical parameters of an optical fibre. The parameters measured will depend on the type of geometry test set

1.2.13
infant fibre
fibre whose geometry is to be measured on a calibrated geometry test set

1.2.14
instrument state
description of the measurement conditions of the geometry test set during calibration and measurement, for instance form-fits used, data filtering schemes employed and other important information concerning the test set such as warm-up time and date of calibration

1.2.15
national standard
standard whose measurement is traceable to fundamental quantities, such as the wavelength of light, and which is used as the basis for fixing the value, in a country, of all other standards of the quantity concerned

1.2.16
national standards laboratory
body or laboratory that maintains and operates the national standard

1.2.17
operating range
range of conditions under which the geometry test set is designed to perform within the stated expanded uncertainty; for example diameter of the fibre being measured and environmental conditions, such as temperature

1.2.18
reference standard
artefact measured at a calibration laboratory, with the measurement traceable to national standards

1.2.19
scaling factor
ratio of the known standard values for a calibration standard to the values indicated by the geometry test set when no correction offsets are applied

1.2.20
standard uncertainty
standard uncertainty may be evaluated either by statistical methods, termed type A evaluation, or by other means, termed type B evaluation (see annex C for a more detailed description).

A type A evaluation of uncertainty consists of a statistical analysis of a series of measurements, such as when evaluating certain random effects of measurement.

A type B evaluation of uncertainty is used when a statistical analysis is not appropriate. It consists of an estimation of the probable sources of uncertainty, such as when evaluating certain systematic effects of measurement.

NOTE – In order to combine standard uncertainties from different sources it is important that they all be stated at the same confidence level. This may be achieved by use of the coverage factor k, which is determined with reference to Student's t distribution for each individual uncertainty component.

1.2.21
traceability
ability to demonstrate, for a measurement result or a geometry test set, a calibration chain originating from a national standard

Geometry test sets calibrated by the procedures in this standard are traceable. Direct traceability of the measurement result to either a national standards laboratory or to an accredited calibration laboratory needs to be demonstrated. Such traceability includes the calibration schedules of all artefacts in the calibration chain and detailed calculations of all (cumulative) transfer uncertainties in the calibration chain. The use of a working standard alone to compare or monitor geometry test set calibration cannot establish or re-establish traceability, but can only extend the duration of the traceability certification if no change is found.

1.2.22
transfer standard
standard that is calibrated against a reference standard and is used for calibrating geometry test sets

1.2.23
transfer uncertainty
estimate characterizing the uncertainty of a measurement caused by uncertainties in the transfer process, at the given confidence level (such as changes in environmental conditions). These uncertainties may arise from the calibration standards used as well as from the geometry test set.

1.2.24
working standard
standard that is usually calibrated against a transfer standard or a reference standard and is used on a routine basis to check geometry test sets

1.3 Geometrical parameters of optical fibres

It is necessary to characterize the geometrical properties of optical fibres in order to ensure satisfactory mechanical and optical performance. The geometrical parameters measured by the types of test sets consist of the following:

a) cladding (reference surface) diameter;

b) cladding non-circularity;

c) core/cladding concentricity error.

NOTE – Geometry measurements on a single-mode fibre are usually performed at a wavelength other than that corresponding to single-mode operation of the fibre. It is, however, generally assumed that the value of mode-field concentricity error of a single-mode fibre is the same as that of core/cladding concentricity error, but this is beyond the scope of this standard.

1.4 Description of geometry test sets

End face image, or grey-scale, test sets usually comprise an optical microscope, an illumination source, an electronic image recording device, such as a camera, and a means of storing image data for processing by digital computer. A second illumination source is usually employed to launch light into the other end of the fibre. This enables the position of the fibre core also to be measured. A typical measurement sequence is as follows: a cleaved fibre end is positioned in the measurement port of the instrument and an image of the fibre end is formed on the camera. The image of the fibre is focused, usually under automatic computer control, digitized, and then transferred to a computer which determines the geometrical parameters of the fibre.

The quality of the fibre end is critical in this method, and the presence of cleave damage, such as chips or edge roughness, can seriously affect the measurement. It is thus usual to employ data-filtering methods to reduce the sensitivity of the measured result to the presence of cleave damage.

1.5 Calibration standard requirements

The calibration procedure detailed in this standard requires the use of traceable calibration artefacts. These artefacts consist of a calibrated fibre end and a chromium-on-glass mask. Their nominal dimensions are discussed in 2.3.3 and 2.5.

2 Calibration

2.1 Introductory remark

The calibration procedure comprises the following two operations.

a) The magnification, or scaling factor, of the imaging system is calibrated. This is a similar process to conventional calibration methods for optical microscopes, except that, in this case, a two-dimensional calibration is required.

b) A correction offset is determined. This offset is required to correct for systematic effects such as diffraction at the fibre edge, differences between the way the calibration artefact is calibrated and the method of measurement in the test set, and distortion of the image of the fibre edge by camera sampling.

   Worked examples for the determination of calibration factors are given in annex B.

NOTE 1 – The calibration will be valid when applied to measurements in the following way:

– the scaling factors are applied multiplicatively to the raw data from the camera, before applying form-fits and computing the cladding diameter of the fibre under test;

– the correction offset is applied additively to the computed cladding diameter of the fibre under test.

NOTE 2 – The choice of an edge-setting criterion defining the position of the cladding edge is important and calibration applies only to measurements using the same criterion as that used at the time of calibration.

NOTE 3 – In certain circumstances it has been found sufficient to calibrate only the scaling factor, using a fibre or chromium-on-glass standard. This approach, however, may lead to increased uncertainties when measuring fibres which are of significantly different diameter from the calibration standard used.

2.2 Rationale for calibration of geometry test sets

The measurement of cladding diameter is common to most types of geometry test sets, so calibration of this parameter is very important in comparing test sets of different types. This standard, however, details only the calibration of test sets which perform end-face image analysis.

Basically, calibration is achieved by exposing the test set to independent geometrical calibration standards. It is these standards that form the calibration chain and, therefore, contribute to the transfer uncertainty.

The procedure is detailed in 2.3. The complete calibration chain is illustrated in figure 1.

Calibration of the core/cladding concentricity error and non-circularity measurement is not described as there are no suitable standard reference materials available at the time of writing. However, procedures enabling estimation of the uncertainties obtained in the measurement of these parameters are given in 2.6 and 2.7 respectively.

2.2.1 Verification of calibration state

For routine verification, such as may frequently be carried out on geometry test sets in use, it is sufficient to check (but not to reset) the state of calibration of the geometry test sets using a working standard. The working standard may be a fibre or a chrome-on-glass mask. A procedure for generation of a working standard is given in annex E.

The distinction between checking the state of calibration and the calibration itself must be clearly made. While it is sufficient to establish stability of the geometry test set using the working standard, this is not a substitute for full calibration.

The use of a working standard allows continued traceability to national standards to be claimed, if it can be satisfactorily established that the existing instrument state, correction factors, and so on, are sufficient to provide geometry results within a specified uncertainty and without alteration. This simply means that the geometry test set has remained stable since the last calibration.

Continued traceability can be claimed on a calibrated test set provided that the measured values for the working standard agree with its calibrated values within the uncertainties.

Calibration is essential in the commissioning of geometry test sets, whereas a working standard is used for routine calibration checking.

The procedure for calibration checking is described in 2.4.

2.3 Calibration procedure

2.3.1 General advice and organization

Ensure that the environmental conditions are commensurate with the working environment as specified by the manufacturer. Employ good metrological practices at all times.

Ensure that all calibration standards used in the calibration are calibrated according to a documented programme with traceability to national standards laboratories or to accredited standards laboratories. If possible maintain more than one standard on each hierarchical level of the calibration chain, so that the performance of standards can be verified by comparisons on the same level.

Develop a documented measurement procedure for each type of calibration performed, giving step-by-step operating instructions and equipment to be used. Use pro-forma result sheets, uncertainty budgets and calibration certificates (see clause 4).

Operate a quality system appropriate to the range of measurements. Ensure that there is independent scrutiny of measurement results, intermediate calculations and calibration certificates are prepared.

2.3.2 Test requirements

a) Perform all tests at a temperature and relative humidity that are within the manufacturer's specification for the test set.

b) Allow sufficient time for the geometry test set and test equipment to reach thermal equilibrium with the environment in accordance with the manufacturer's recommendations for the test set and the calibration standards used, before commencing the calibration procedure.

c) Set up the geometry test set to the appropriate settings for calibration procedures, as recommended by the manufacturer.

d) Ensure, where possible, that all accessible optical surfaces and calibration standards are clean before measurement.

2.3.3 Calibration standard requirements

The use of calibration standards which are traceable to national standards laboratories is mandatory. The calibration procedure requires the use of the following:

a) A fibre end with calibrated cladding diameter. The fibre should be of similar material to and within 5,0 µm of the nominal cladding diameter of the fibres to be measured by the test set and have a non-circularity of less than 0,5 %.

NOTE 1 – The calibrated fibre end must not be re-cleaved. This is due to variations of diameter along the length of the fibre.

NOTE 2 – If the fibre end becomes damaged or cannot be cleaned sufficiently, it should not be used for the purpose of calibration.

b) A calibrated measurement scale. This is a chromium-on-glass mask with a pattern, typically, of dots, lines, circles or annuli.

For calibration checking (see 2.4), the standard may be either a fibre or a chromium-on-glass pattern with traceable geometry values.

2.3.4 Determination of calibration factors

A derivation of the calibration factors used is given in annex A.

2.3.4.1 Scaling factor

To calibrate the scaling factor use a chromium-on-glass mask. This may comprise an array of dots or lines, or an annular structure. The principle of calibration is to measure the distance between graduations.

NOTE – The uniformity of the scaling factor over the field of view of the imaging system (known as spatial linearity) will affect the uncertainty that can be transferred to measurements on fibres and also to measurements of core/cladding concentricity error. A method for estimating spatial linearity is described in 2.5.

The scaling factors for the *x* and *y* axes of the camera are given by:

$$S_x = \frac{Dx_c}{Dx_m} \tag{1}$$

$$S_y = \frac{Dy_c}{Dy_m} \tag{2}$$

where

Dx_m is the measured spacing of graduations along the *x*-axis;

Dy_m is the measured spacing of graduations along the *y*-axis;

Dx_c is the calibrated spacing of graduations along the *x*-axis;

Dy_c is the calibrated spacing of graduations along the *y*-axis.

The procedure to measure the distance between graduations will depend on the type of chrome mask used, as follows:

a) Regular array of dots or lines

Form an image of the array in a manner consistent with normal operation of the test set. Measure the distances between graduations in two orthogonal directions, these being parallel to the scan axes of the camera.

NOTE 1 – The distance over which calibration is effected should be within 5 µm of the nominal diameter of the fibres to be measured by the test set.

NOTE 2 – It is desirable to align the axes of the array to be parallel to the scan axes of the camera. However, if they are not so aligned, compensation for the angular misalignment needs to be applied.

b) Annulus

Form an image of the annulus in a manner consistent with normal operation of the test set. Apply elliptical form fits to the inner and outer edges of the annulus. Determine the measured diameters Dx_m and Dy_m along the *x* and *y* axes as follows:

$$Dx_m = \frac{Dx_{inner} + Dx_{outer}}{2} \tag{3}$$