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Edition 3.0 2023-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Calibration of fibre optic chromatic dispersion test sets

Étalonnage des ensembles d'essai de la dispersion chromatique fibronique

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CALIBRATION OF FIBRE OPTIC CHROMATIC DISPERSION TEST SETS

FOREWORD

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IEC 61744 has been prepared by IEC technical committee 86: Fibre optics. It is an International Standard.

This third edition cancels and replaces the second edition published in 2005. This edition constitutes a technical revision.

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

a) updated terms and definitions;
b) the use of a reference fibre standard for calibration is now allowed and at the same level as the other calibration method;
c) Annex B was split into a new Annex B (on calibration uncertainty, still normative) and a new Annex C (on uncertainty at operating conditions, informative);
d) removed former C.3.4 on interferometric method since this method is no longer supported in IEC 60793-1-42;
e) removed Annex D and other references in text to calibration compensation to align with other calibration documents;

f) removed Annex E and other references in text to use of air wavelength since it is not used in the fibre domain.

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

Draft	Report on voting
86/615/FDIS	86/617/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under 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- withdrawn,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.

0 Introduction

0.1 Chromatic dispersion in optical fibres

Chromatic dispersion is the variation with optical light wavelength of the light propagation delay time in a length of fibre. This variation can cause bandwidth limitation in the fibre when used to transmit communication signals. For a more detailed explanation, refer to Annex D and IEC 60793-1-42.

0.2 Chromatic dispersion (CD) test sets

CD test sets are used to measure the chromatic dispersion properties of optical fibres and typically comprise an optical source of known wavelength(s), a fibre light input coupling and output coupling means, optical detection means, and electronic or optical means of determining the optical delay or dispersion at the source wavelength. There are several variants each requiring slightly different calibration techniques. Refer to Annex D for further details.

In general, all CD test sets produce an output of fibre delay or dispersion versus the light wavelength, typically in graphical form.

In essence, all CD test sets operate with wavelength as a programmed (independent) variable, usually the abscissa (x-axis) and dispersion or time delay as the ordinate (y-axis) as a measured (dependent) variable. By their nature, fibre chromatic dispersion measurements require multiple wavelengths to be programmed. Even in the case of a single dispersion point obtained using the differential phase shift method, two separate wavelength values are used. It is also typical to expect a wide range of dispersion values over a range of wavelengths to be measured.

0.3 Overview of calibration procedures described in this document

The requirement to calibrate the CD test set, traceable to known standards, is essential for quality control in fibre optic production, fibre research and similar activities. This document describes the detailed procedures used to establish calibration of a CD test set.

Calibration of a CD test set is established by applying known artefacts or standards (themselves calibrated to reference standards) to the CD test set and measuring its response.

Primarily, the artefacts or standards used are as follows.

a) Wavelength artefact(s) or traceable wavelength measuring instruments used to calibrate the light source wavelength(s) used by the CD test set. This is to establish the correct excitation wavelength for the system (the "x-axis").

b) Delay or dispersion artefact(s) used to calibrate the delay or dispersion response of the CD test set (the "y-axis").

c) Traceable chromatic dispersion reference fibre used to calibrate the CD test set. This method allows a simultaneous calibration of the whole CD test set, including the measurement of the delay or dispersion response of the CD test set as a function of wavelength and also the internal data processing part. A proper selection of the type of reference fibre is important, especially for an accurate calibration of the zero dipersion wavelength.

Calibration can only be carried out using these artefacts; the use of a known standard fibre (reference fibre described in c)) whose chromatic dispersion is known is recommended as the fibre forms a stable source of known dispersion and may be used as a simple dispersion artefact.

If it is found that the CD test set measurement results have changed significantly compared to the user requirements (i.e. the test set has drifted by more than the repeatability), then adjustment may be carried out depending on the need.

In this document, the reference medium for wavelength and the velocity of light is assumed to be in vacuum, and hence define the refractive index = 1,000 000 0.

CALIBRATION OF FIBRE OPTIC CHROMATIC DISPERSION TEST SETS

1 Scope

This document provides standard procedures for the calibration of optical fibre chromatic dispersion (CD) test sets.

This document is applicable to all types of CD test sets, with the exception that measurements on multimode optical fibres are excluded.

The purpose of this document is to define a standard procedure for calibrating optical fibre chromatic dispersion (CD) test sets. The detailed calibration steps used vary according to the measurement technique used in the CD test set.

Whilst it is acknowledged that chromatic dispersion also occurs in multimode fibre and this fibre can be measured on many CD test sets, this document will restrict discussion to single mode fibre measurements applications only.

The purpose of the procedures outlined in this document is to focus manufacturers and users of CD test sets toward the reduction of measurement uncertainty in chromatic dispersion determination in optical fibres under all applicable conditions. The procedures apply to calibration laboratories and to the manufacturers or users of CD test sets for the purpose of

a) calibrating CD test sets, and

b) evaluating the level of performance of the instrument.

Use of the procedures also allows correct evaluation of CD test set uncertainty, relative and traceable to appropriate (for example, national) standards.

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 60050-731, *International Electrotechnical Vocabulary (IEV) – Chapter 731: Optical fibre communication*, available at www.electropedia.org

IEC 62129-1, *Calibration of wavelength/optical frequency measurement instruments – Part 1: Optical spectrum analyzers*

IEC 62129-2, *Calibration of wavelength/optical frequency measurement instruments – Part 2: Michelson interferometer single wavelength meters*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions contained in IEC 60050-731 and the following apply.

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

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

3.1
accredited calibration laboratory
calibration laboratory authorized by the appropriate national standards laboratory to issue calibration certificates with a minimum specified uncertainty that demonstrate traceability to national standards

3.2
adjustment
set of operations carried out on an instrument in order that it provides given indications corresponding to given values of the measurand

3.3
artefact
device, instrument, or equipment used in the process of calibrating a CD test set for wavelength, delay, or chromatic dispersion

3.4
calibration
set of operations that establish, under specified conditions, the relationship between the values of quantities indicated by a measuring instrument and the corresponding values realized by measurement standards

Note 1 to entry: The result of a calibration permits either the assignment of values of measurands to the indications or the determination of corrections with respect to indications.

Note 2 to entry: A calibration may also determine other metrological properties such as the effect of influence quantities.

Note 3 to entry: The result of a calibration may be recorded in a document, sometimes called a calibration certificate or a calibration report.

Note 4 to entry: See also ISO/IEC Guide 99:2007, 2.39.

3.5
traceability chain
unbroken chain of comparison using standards

Note 1 to entry: See Figure 1.

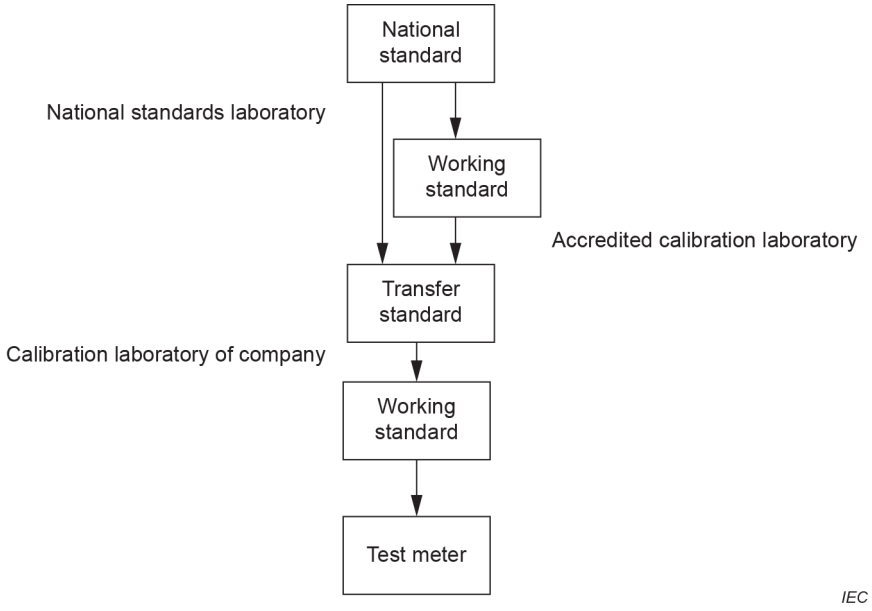

Figure 1 – Example of a traceability chain

3.6
centroidal wavelength
power-weighted mean wavelength of a light source in vacuum

Note 1 to entry: For a continuous source spectrum, the centroidal wavelength λ_c in vacuum is defined by the following integral, where the integration limits enclose the entire spectrum of the source. However, it is usually sufficient to perform the integral or summation over the spectrum where the spectral density $p(\lambda)$ or power P_i is higher than 0,1 % of the maximum spectral density $p(\lambda)$ or power P_i:

$$\lambda_c = (1/ P_{total}) \times [\int p(\lambda) \times \lambda \, d\lambda] \quad (1)$$

where

$P_{total} = \int p(\lambda) \, d$ is the total optical source power.

For a spectrum consisting of i discrete lines, the centroidal wavelength in vacuum λ_c is defined as:

$$\lambda_c = (1/ P_{total}) \times \left[\sum_i p_i \lambda_i \right] \quad (2)$$

where

$p(\lambda)$ is the spectral power spectral density of the source in W/nm;

λ_c is the centroidal wavelength in vacuum in nanometers;

λ_i is the i^{th} discrete line in nm;

p_i is the power levels at λ_i in W;

$P_{total} = \sum_i p_i$ is the total power in W.

3.7
chromatic dispersion (CD) test sets
instrument capable of measuring the chromatic dispersion of a single mode fibre at various wavelengths in the transmission windows of interest

Note 1 to entry: Windows of interest are typically the 1 310 nm and/or 1 550 nm wavebands.

3.8
correction offset
CO
number that is added to or subtracted from the measurement result of a CD test set to correct for a known physical effect or deviation

3.9
instrument state
complete description of the measurement conditions and state of the CD test set during the calibration process

Note 1 to entry: Typical parameters of the instrument state are the wavelength range in use, the data fit model (as applicable), warm-up time, and other instrument settings.

3.10
measurement result
displayed or electrical output of any CD test set, in

- dispersion D in units of ps × nm^{-1} × km^{-1},
- lambda zero λ_0 in units of nm,
- zero dispersion slope S_0 in units of ps × nm^{-2} × km^{-1},

after completing all actions suggested by the operating instructions, for example warm-up

3.11
national standard
standard recognized by a national decision to serve in a country as the basis for assigning values to other standards of the quantity concerned

Note 1 to entry: For more information, see ISO/IEC Guide 99:2007, 5.3.

3.12
national standards laboratory
national metrology institute
laboratory which maintains the national standard

3.13
operating conditions
appropriate set of specified ranges of values of influence quantities usually wider than the reference conditions for which the uncertainties of a measuring instrument are specified

3.14
reference standard
standard, generally having the highest metrological quality available at a given location or in a given organization, from which measurements made therein are derived

Note 1 to entry: For more information, see ISO/IEC Guide 99:2007, 5.6.

3.15
scaling factor
SF
ratio of known standard values for a standard artefact to the values indicated by the CD test set when no correction offsets are applied

Note 1 to entry: The factors can apply to wavelength, delay (dispersion) calibration, as well as to recorded zero dispersion wavelength, slope and actual dispersion data values when using a calibrated reference fibre.

3.16
spectral bandwidth
B
full-width at half-maximum (FWHM) of the source spectrum

Note 1 to entry: If the source is a laser diode with a multiple-longitudinal mode spectrum, then the FWHM spectral bandwidth B is the RMS spectral bandwidth, multiplied by 2,35 (assuming the source has a Gaussian envelope):

$$B = 2{,}35 \times [\{ (1/ P_{\text{total}}) \times (\sum_i p_i \lambda_i^2)\} - \lambda_c^2]^{½} \quad (3)$$

where

λ_c is the centroidal wavelength (see 3.6) of the laser diode, in nm;

$P_{\text{total}} = \sum_i p_i$ is the total power, in W;

p_i is the power of i^{th} longitudinal mode, in W;

λ_i is the vacuum wavelength of i^{th} longitudinal mode, in nm.

3.17
traceability
property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties

Note 1 to entry: For more information, see ISO/IEC Guide 99:2007, 2.41.

3.18
transfer standard
reference standard
standard, generally having the highest metrological quality available at a given location or in a given organization, from which measurements made therein are derived, and used to calibrate working standards

3.19
working standard
standard that is used routinely to calibrate measuring instruments

Note 1 to entry: A working standard is usually calibrated against a transfer standard (3.18).

Note 2 to entry: For more information, see ISO/IEC Guide 99:2007, 5.7.

4 Calibration

4.1 General

Clause 4 summarizes the action of calibrating a chromatic dispersion (CD) test set and details the recommendations for the environmental requirements of the calibration facility.

4.2 Preparation for calibration

4.2.1 General advice and organization

The accreditation calibration laboratory should ensure that suitable requirements for calibration are followed.

NOTE Guidance about good practices for calibration are in ISO/IEC 17025 [1][1].

There should be a documented measurement procedure for each type of calibration performed, giving step-by-step operating instructions and equipment to be used.

4.2.2 Environmental conditions requirements

The following requirements shall be observed:

a) all tests shall be performed at an ambient temperature of 23 °C ± 3 °C (or tighter);

b) the CD test set, test apparatus and equipment shall be given sufficient time to reach thermal equilibrium with the environment in accordance with the manufacturer's recommendations for each item of equipment, before commencement of any part of the calibration procedure;

c) the instrument state of the CD test set and test equipment shall be recorded, a precondition for reproducible measurements;

d) connectors and optical input ports, etc. should always be cleaned before measurement.

If the current calibration conditions are different from those of the calibration standards, make sure that the calibration standards remain traceable with the required level of uncertainty.

4.2.3 Measurement equipment requirements

Calibration of test equipment with traceability described in 4.2.4 is mandatory. The tests described require the use of some or all of the following:

a) a variable optical attenuator;

b) a wavelength measuring device (an optical spectrum analyzer calibrated according to IEC 62129-1 or wavelength meter calibrated according to IEC 62129-2) for discrete wavelength sources such as lasers;

c) a wavelength standard (for example, He-Ne laser or other wavelength standard) for tuneable monochromator-based systems;

d) an optical delay line artefact (differential optical delay line artefact) for delay (dispersion) calibration;

e) a calibrated chromatic dispersion reference fibre.

4.2.4 Traceability

Ensure that all test equipment which has significance to the calibration result has been calibrated in an unbroken traceability chain to the appropriate national standard. The recalibration period(s) shall be defined and documented. The details of traceability for this test equipment shall be made available on request (see Clause 7).

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1 Numbers in square brackets refer to the Bibliography.

4.3 Calibration procedure

The calibration methods for all types of CD test sets calibrate either

a) the source wavelength(s), and the delay (dispersion) response of the set separately, which allows determining relevant correction offset and/or scaling factors for both quantities separately, or

b) the full test set in a single measurement, using a calibrated chromatic dispersion reference fibre, which allows determining relevant offsets for chromatic dispersion, dispersion slope and zero dispersion wavelength.

In case a), the user shall first ascertain which type of light source(s) (for example lasers or LED/filter/ monochromator) is in use and which measurement technique is in use in the CD test set.

Some CD test sets can perform more than one measurement technique, in which case it would be necessary to separately calibrate the CD test set for all measurement techniques in use, under the auspices of this document.

For each CD test set calibration, the procedure consists of the following.

a) Use the procedure appropriate to the CD test set measurement method for
   1) calibration of the wavelength parameter (see 5.1):
      i) for discrete wavelength source systems, use the procedure of 5.1.2;
      ii) for continuously tuneable source systems, use the procedure of 5.1.3.
   2) Use equipment appropriate to the CD test set measurement method; calibrate the delay parameter using the procedure of 5.2.3.

b) Or, instead of the procedures in a), only calibrate the chromatic dispersion using the procedure of Clause 6.

c) Report and record on a certificate the calibration results according to Clause 7. The CD test set is now fully calibrated to national standards with the specified uncertainty.

5 Wavelength and delay calibration procedure

5.1 Wavelength calibration procedure

5.1.1 General

5.1 describes procedures for calibration of wavelength in CD test sets. The technical principle is to apply calibrated wavelength artefacts such as external sources, optical transmission elements or other artefacts to determine the centroidal wavelength(s) used in the CD test set for dispersion measurement. The actual wavelengths used may then be adjusted. The process of calibration differs according to the light source used in the CD test set under consideration. For sets using lasers or other discrete wavelength sources, see 5.1.2; for continuously variable (tuneable) sources, see 5.1.3. In either case, see 5.1.4 to report the calibration results.

5.1.2 Discrete sources

Many CD test sets use discrete laser diodes or discrete filtered LED/lamp sources, and the procedure below shall be used to calibrate the wavelength. Any additional measurement apparatus, artefact or equipment used in this calibration procedure shall be prior calibrated to traceable standards. In these instruments, the following procedure shall be used.

a) Establish that the test equipment requirements have been met (see 4.2.3).

b) Establish that the test environmental conditions have been met (see 4.2.2).

c) Set up the CD test set instrument state to the appropriate settings for calibration procedures (see 4.2.2).