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Calibration of fibre optic chromatic dispersion test sets

Etalonnage des ensembles d'essai de la dispersion chromatique des fibres optiques

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

CALIBRATION OF FIBRE OPTIC CHROMATIC DISPERSION 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.
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International Standard IEC 61744 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
86/170/FDIS	86/173/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 3.

Annexes A and B form an integral part of this standard.

Annexes C and D are for information only.

The committee has decided that the contents of this publication will remain unchanged until 2002. At this date, the publication will be

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- withdrawn;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

INTRODUCTION

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 C and IEC 60793-1-1.

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 C 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. Thus, wavelength constitutes the 'x-axis' and delay or dispersion the 'y-axis'.

Overview of calibration procedures described in this standard

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 standard 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, measuring its response and adjusting (correcting) the CD test set to achieve results that match the standards used. In this way the CD test set results will be brought to close agreement with other CD test sets also calibrated in the manner described in this standard.

Primarily the artefacts or standards used are as follows:

a) wavelength artefact(s) 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') in order that the correct delay or dispersion (the 'y-axis') be determined subsequently;

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

Calibration can only be carried out using these artefacts. After a calibration has been completed, a calibration period is defined over which the CD test set is deemed to remain calibrated. At the end of this period, it would be necessary to establish if the CD test set calibration requires updating (changing); this can be performed using the artefact described above, or by use of a known standard fibre (reference fibre) whose chromatic dispersion is known. This is referred to as calibration checking. The fibre forms a stable source of known dispersion and may be used as a simple dispersion artefact.

If it is found that the calibration has not changed within the required uncertainty limits, then it is possible to simply extend the calibration period again by a defined amount.

If, however, 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), then calibration using the artefacts (if not already carried out at this time) should be carried out and the calibration renewed.

The above rationale ensures that the CD test set calibration is only ever performed using known standards (artefacts), but that if the CD test set is sufficiently stable over the calibration period selected, then a simple check of calibration can suffice to ascertain this and to (justify) allow the extension of the calibration period. The extension can be repeated indefinitely over many calibration periods, provided the CD test set continues to remain within uncertainty limits over the entire set of calibration periods.

In order to be considered calibrated and in conformance with this standard, a CD test set must have its calibration adjusted based on comparison to artefacts for the primary parameters of wavelength and delay [dispersion]. In all cases, this calibration of primary parameters is necessary, but may or may not be sufficient, to ensure calibration of the CD test set to the required uncertainty.

In addition, it may be necessary to also confirm or compensate the calibration state of a CD test set using a calibrated reference fibre. The CD test set calibration compensation is explained more fully in annex D. It should be noted that use of a calibrated reference fibre alone is not sufficient to ensure calibration of a CD test set.

It should also be noted that if a calibrated CD test set undergoes calibration compensation using a calibrated reference fibre, the scope and extent of its calibration is limited to the conditions used at the time of calibration compensation (i.e. wavelength, fibre type, loss regime, etc.) Care should be exercised that test sets calibrated and compensated in this manner are used only within the appropriate limits of their calibration extent. The adjustments required to effect compensation on one set of wavelengths for one fibre type may increase the uncertainty of measurement of other fibre types with different minimum dispersion wavelengths.

CALIBRATION OF FIBRE OPTIC CHROMATIC DISPERSION TEST SETS

1 Scope

This International Standard provides standard procedures for the calibration of optical fibre chromatic dispersion (CD) test sets. It also provides procedures to perform calibration checking on CD test sets whereby an extension to the test set calibration period may be obtained.

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

The purpose of this standard 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 may be measured on many CD test sets, this standard will restrict discussion to single mode fibre measurements only.

The purpose of the procedures outlined in this standard 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,

b) setting specifications of CD test sets,

c) extending the calibration period of an already calibrated CD test set.

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 normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(731):1991, *International Electrotechnical Vocabulary (IEV) – Chapter 731: Optical fibre communication*

IEC 60793-1-1:1995, *Optical fibres – Part 1: Generic specification – Section 1: General* [1)]

IEC 60825-1:1993, *Safety of laser products – Part 1: Equipment classification, requirements and user's guide* [2)]

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1) A consolidated edition 1.1 exists (1999) that includes IEC 60793-1-1 (1995) and its amendment 1 (1998).

IEC 62129, *Calibration of optical spectrum analyzers* [3)]

ISO 9000 (all parts), *Quality management and quality assurance standards*

ISO 10012-1:1992, *Quality assurance requirements for measuring equipment – Part 1: Metrological confirmation system for measuring equipment*

ISO 10012-2:1997, *Quality assurance for measuring equipment – Part 2: Guidelines for control of measurement processes*

Guide to the Expression of Uncertainty in Measurement, 1993, ISO, ISBN 02-67-10188-9

EN 45001:1989, *General criteria for the operation of testing laboratories*

3 Terms and definitions

For the purpose of this International Standard, IEC 60050(731) and the following definitions apply.

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

3.2
adjustment
modifying the hardware or firmware of a CD test set with the intention of making the measurement result of the CD test set equal to that of a national standard or a similar calibrated CD test set. This has the effect of correcting all subsequent measurements on that CD test set

3.3
artefact
device, instrument or equipment used in the process of calibrating a CD test set, for both wavelength and delay [dispersion]. The artefact is a means of transferring calibration of these parameters to a CD test set

3.4
calibration
process by which the relationship between the values indicated by the infant CD test set and known values of the calibration standard is established under specified conditions. The intention of calibration is to bring all CD test sets into substantial agreement with a suitable national standards laboratory. This may be performed by first comparing the relevant parameter of a measurement artefact with that produced by the CD test set, followed by transfer of that result, either by adjustment of the CD test set or by documentation of a calibration factor(s) in a calibration certificate. The pertaining environmental conditions and instrument state are usually recorded. Calibration includes estimation of all uncertainties. The use of reference fibres is for calibration checking only

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[2)] A consolidated edition 1.1 exists (1998) that includes IEC 60825-1 (1993) and its amendment 1 (1997).

[3)] To be published.

3.5
calibration chain
unbroken chain of transfers from a primary standard to the CD test set via reference standards, intermediate and/or working standards (see figure 1)

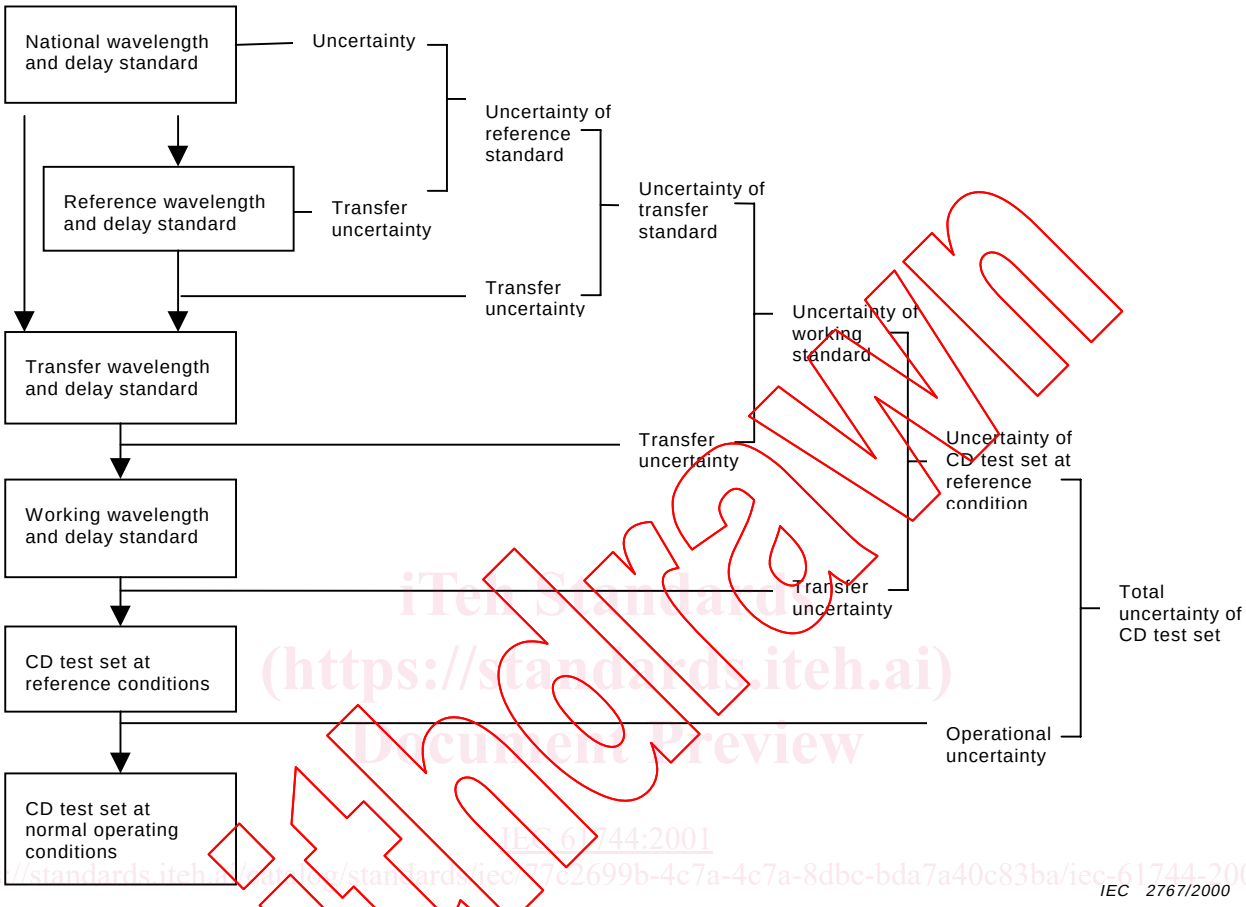

Figure 1 – Typical calibration chain for CD test sets

3.6
calibration checking
process of establishing that a CD test set which has been previously calibrated, but is nearing the end of its calibration period, remains within specified uncertainty limits. If the CD test set has drifted outside these limits, then calibration is required. Otherwise, the calibration period can be extended for a stated period, and calibration checking may be repeated indefinitely if the CD test set remains stable over successive calibration periods. Calibration checking is performed using a reference fibre or working standard. Essentially calibration checking is the first part of the process of calibration, but without the additional process of transfer or adjustment

3.7
calibration period
interval of confirmation
time period over which a calibration performed in accordance with the procedures in this standard is deemed to remain within the uncertainty limits set. (i.e. remain valid). The time allotted will be governed by individual user requirements, CD test set characteristics, past experience, environmental conditions, etc. and by monitored CD test set measurement result experience in normal use (see also ISO 10012-1 and ISO 10012-2)

3.8
calibration standard
artefact that is calibrated against a reference standard and is used to calibrate CD test sets. The artefact may be a delay [dispersion] or a wavelength standard artefact. Proper use of the calibration standard ensures traceability. The term includes the national standard, reference standard, the transfer standard and the working standard in descending order of metrological uncertainty

3.9
central wavelength
power-weighted mean wavelength of a light source in air, in units of nanometers (nm)

For a continuous source spectrum, the central wavelength λ_c in air is defined by the following integral, where the integration limits enclose the entire spectrum of the source:

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

where

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

For a spectrum consisting of i discrete lines, the centre wavelength in air 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 density of the source in W/nm;

λ_c is the central wavelength in air 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.

3.10
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, typically the 1 310 nm and/or 1 550 nm wavebands

3.11
combined standard uncertainty
combination of a number of individual standard uncertainties

NOTE The term “accuracy” should be avoided in this context.

All calibration reports and technical data sheets should report the combined standard uncertainty of the CD test set as an overall expanded uncertainty, *U*, with the applicable confidence level, for example 95,5 % or 99,7 %.

3.12
confidence level
estimation of the probability that the true value of a measured parameter lies in the given range (the expanded uncertainty)

3.13
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 systematic uncertainty

3.14
coverage factor, *k*
used to calculate the expanded uncertainty, *U*, from the standard uncertainty σ (see 3.15)

3.15
expanded uncertainty, *U*
(confidence interval)
range of values within which the measurement parameter, at the stated confidence level, can be expected to lie. It is equal to the coverage factor k times the standard uncertainty σ :

$$U = k \times \sigma \qquad (3)$$

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 of k of 1, 2 and 3, respectively.

The measurement uncertainty of a CD test set should be specified in the form of expanded uncertainty *U*.

3.16
infant reference fibre
fibre whose dispersion is measured against a parent reference fibre. The infant reference fibre would then be intended for calibration checking of a CD test set

3.17
instrument state
complete description of the measurement conditions and state of the CD test set during the calibration process

NOTE 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.

3.18
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, or 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.

3.19
national standard
standard whose measurement is traceable to fundamental properties, such as the speed of light, which is recognized by an official national decision and used as the basis for fixing the value, in a country, of all other standards of the quantity concerned

3.20
national standards laboratory
body or laboratory that maintains and operates the national standard

3.21
operating range
all conditions of, for example the dispersion, temperature and other influencing quantities, over which the CD test set is designed to perform within the stated expanded uncertainty

3.22
parent reference fibre
reference fibre which is used as the reference for generating an infant reference fibre. The parent reference fibre may be used for calibration checking of a CD test set

3.23
reference standard
artefact calibrated against a national standard and used to calibrate CD test sets. The artefact may be a delay [dispersion] or wavelength standard artefact. Proper use of the calibration standard ensures traceability. The term includes the national standard, reference standard, the transfer standard and the working standard in descending order of metrological uncertainty

NOTE In this standard, reference standard can also be taken to mean the fibre (infant or parent) which is used as the reference for calibration checking of a CD test set.

3.24
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 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 (see annex D)

3.25
spectral bandwidth
full-width half-maximum (FWHM) spectral width of the source

If the source exhibits a continuous spectrum, then the spectral bandwidth, B, shall be the full-width-half-maximum (FWHM) of the spectrum.

If the source exhibits a spectrum consisting of i discrete line (for example, a laser diode with a multiple-longitudinal mode spectrum), then the FWHM spectral bandwidth B shall be the r.m.s. spectral bandwidth, multiplied by 2,35 (assuming the source has a Gaussian envelope):

$$B = 2{,}35 \times [\{ (1/ P_{total}) \times (\sum_i p_i \ \lambda_i^2)\} - \lambda_c^2]^{½} \qquad (4)$$

where

λ_c is the central wavelength (see 3.9) of the laser diode, in nm;

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

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

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

3.26
standard uncertainty
standard deviation
uncertainty of a measurement result expressed as a standard deviation σ

For further information, refer to annex A, and the *Guide to the Expression of Uncertainty in Measurement.*

NOTE In order to combine standard uncertainties from different sources (see annex A) it is important that they are all stated at the same confidence level, i.e. for normally distributed data, at a confidence level of 68,3 %. This may be achieved by the use of each respective coverage factor k which is determined with reference to student's t-distribution for each individual uncertainty component.

3.27
traceability
ability to demonstrate, for a measurement result or a CD test set, an unbroken calibration chain originating from a national standard

CD test sets calibrated by the procedures of this standard are traceable. In the sense of this standard, direct traceability of the measurement result to either a national standards laboratory or to an accredited calibration laboratory is 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 reference fibre or working standard alone to compare/monitor CD test set calibration will not establish or re-establish traceability, but only extend the duration of the traceability certification (calibration period) if no change is found.