BS EN 61757-1:2012

BSI Standards Publication

Fibre optic sensors

Part 1: Generic specification

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National foreword

This British Standard is the UK implementation of EN 61757-1:2012. It is identical to IEC 61757-1:2012. It supersedes BS EN 61757-1:1999 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee GEL/86, Fibre optics, to Subcommittee GEL/86/3, Fibre optic systems and active devices.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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English version

Fibre optic sensors - Part 1: Generic specification
(IEC 61757-1:2012)

Capteurs a fibres optiques -
Partie 1: Spécification générique
(CEI 61757-1:2012)

LWL-Sensoren -
Teil 1: Fachgrundspezifikation
(IEC 61757-1:2012)

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CENELEC

European Committee for Electrotechnical Standardization
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Foreword

The text of document 86C/1059/FDIS, future edition 2 of IEC 61757-1, prepared by SC 86C, "Fibre optic systems and active devices", of IEC TC 86, "Fibre optics" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61757-1:2012.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2013-03-19
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2015-06-19

This document supersedes EN 61757-1:1999.

EN 61757-1:2012 includes a substantial technical update of all clauses, definitions, and cited references with respect to EN 61757-1:1999.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 61757-1:2012 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60654-4	NOTE Harmonized as EN 60654-4.
IEC 60721-1	NOTE Harmonized as EN 60721-1.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050	-	International Electrotechnical Vocabulary (IEV)	-	-
IEC 60060-1	-	High-voltage test techniques - Part 1: General definitions and test requirements	EN 60060-1	-
IEC 60068-1	-	Environmental testing - Part 1: General and guidance	EN 60068-1	-
IEC 60068-2-1	-	Environmental testing - Part 2-1: Tests - Test A: Cold	EN 60068-2-1	-
IEC 60068-2-2	-	Environmental testing - Part 2-2: Tests - Test B: Dry heat	EN 60068-2-2	-
IEC 60068-2-5	-	Environmental testing - Part 2-5: Tests - Test Sa: Simulated solar radiation at ground level and guidance for solar radiation testing	EN 60068-2-5	-
IEC 60068-2-6	-	Environmental testing - Part 2-6: Tests - Test Fc: Vibration (sinusoidal)	EN 60068-2-6	-
IEC 60068-2-10	-	Environmental testing - Part 2-10: Tests - Test J and guidance: Mould growth	EN 60068-2-10	-
IEC 60068-2-11	-	Basic Environmental testing procedures - Part 2: Tests - Test Ka: Salt mist	EN 60068-2-11	-
IEC 60068-2-13	-	Basic Environmental testing procedures - Part 2: Tests - Test M: Low air pressure	EN 60068-2-13	-
IEC 60068-2-14	-	Environmental testing - Part 2-14: Tests - Test N: Change of temperature	EN 60068-2-14	-
IEC 60068-2-27	-	Environmental testing - Part 2-27: Tests - Test Ea and guidance: Shock	EN 60068-2-27	-
IEC 60068-2-30	-	Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle)	EN 60068-2-30	-
IEC 60068-2-42	-	Environmental testing - Part 2-42: Tests - Test Kc: Sulphur dioxide test for contacts and connections	EN 60068-2-42	-
IEC 60068-2-43	-	Environmental testing - Part 2-43: Tests - Test Kd: Hydrogen sulphide test for contacts and connections	EN 60068-2-43	-

Publication	Year	Title	EN/HD	Year
IEC 60068-2-78	-	Environmental testing - Part 2-78: Tests - Test Cab: Damp heat, steady state	EN 60068-2-78	-
IEC 60079-28	-	Explosive atmospheres - Part 28: Protection of equipment and transmission systems using optical radiation	EN 60079-28	-
IEC 60529	-	Degrees of protection provided by enclosures (IP Code)	EN 60529	-
IEC 60695-11-5	-	Fire hazard testing - Part 11-5: Test flames - Needle-flame test method - Apparatus, confirmatory test arrangement and guidance	EN 60695-11-5	-
IEC 60793-1-1	-	Optical fibres - Part 1-1: Measurement methods and test procedures - General and guidance	EN 60793-1-1	-
IEC 60793-1-54	-	Optical fibres - Part 1-54: Measurement methods and test procedures - Gamma irradiation	EN 60793-1-54	-
IEC 60793-2	-	Optical fibres - Part 2: Product specifications - General	EN 60793-2	-
IEC 60794-1-1	-	Optical fibre cables - Part 1-1: Generic specification - General	EN 60794-1-1	-
IEC 60794-1-2	-	Optical fibre cables - Part 1-2: Generic specification - Basic optical cable test procedures	EN 60794-1-2	-
IEC 60825-1	-	Safety of laser products - Part 1: Equipment classification and requirements	EN 60825-1	-
IEC 60874-1	-	Fibre optic interconnecting devices and passive components - Connectors for optical fibres and cables - Part 1: Generic specification	EN 60874-1	-
IEC 61000-4-2	-	Electromagnetic compatibility (EMC) - Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test	EN 61000-4-2	-
IEC 61000-4-3	-	Electromagnetic compatibility (EMC) - Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test	EN 61000-4-3	-
IEC 61000-4-4	-	Electromagnetic compatibility (EMC) - Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test	EN 61000-4-4	-
IEC 61000-4-5	-	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test	EN 61000-4-5	-
IEC 61300	Series	Fibre optic interconnecting devices and passive components - Basic test and measurement procedures	EN 61300	Series

Publication	Year	Title	EN/HD	Year
IEC 61300-2-18	-	Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 2-18: Tests - Dry heat - High temperature endurance	EN 61300-2-18	-
IEC 61300-2-22	-	Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 2-22: Tests - Change of temperature	EN 61300-2-22	-
IEC 61300-2-34	-	Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 2-34: Tests - Resistance to solvents and contaminating fluids of interconnecting components and closures	EN 61300-2-34	-
IEC 61300-2-46	-	Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 2-46: Tests - Damp heat cyclic	EN 61300-2-46	-
IEC 61300-3-35	-	Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 3-35: Examinations and measurements - Fibre optic connector endface visual and automated inspection	EN 61300-3-35	-
IEC 61753	Series	Fibre optic interconnecting devices and passive components performance standard	EN 61753	Series
IEC/TR 61931	-	Fibre optic - Terminology	-	-
IEC/TR 62222	-	Fire performance of communication cables installed in buildings	-	-
IEC/TR 62283	-	Optical fibres - Guidance for nuclear radiation tests	-	-
IEC/TR 62362	-	Selection of optical fibre cable specifications relative to mechanical, ingress, climatic or electromagnetic characteristics - Guidance	-	-
IEC/TR 62627-01	-	Fibre optic interconnecting devices and passive components - Part 01: Fibre optic connector cleaning methods	-	-
ISO/IEC Guide 98-3	-	Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)	-	-
ISO/IEC Guide 99	-	International vocabulary of metrology - Basic and general concepts and associated terms (VIM)	-	-

CONTENTS

FIBRE OPTIC SENSORS –

Part 1: Generic specification

1 Scope

This part of IEC 61757 is a generic specification covering optical fibres, components and subassemblies as they pertain specifically to fibre optic sensing applications. It has been designed to be used as a common working and discussion tool by the vendor of components and subassemblies intended to be integrated in fibre optic sensors, as well as by designers, manufacturers and users of fibre optic sensors independent of any application or installation.

The objective of this generic specification is to define, classify and provide the framework for specifying fibre optic sensors, and their specific components and subassemblies. The requirements of this standard apply to all related sectional, family, and detail specifications. Sectional specifications will contain requirements specific to sensors for particular quantities subject to measurement. Within each sectional specification, family and detail specifications contain requirements for a particular style or variant of a fibre optic sensor of that sectional specification.

A fibre optic sensor contains an optical or optically powered sensing element in which the information is created by reaction of light to a measurand. The sensing element can be the fibre itself or an optically powered element inserted along the optical path. In a fibre optic sensor, one or more light parameters are directly or indirectly modified by the measurand somewhere in the optical path, contrary to an optical data link where the information is merely transmitted from the transmitter to the receiver.

Generic tests or measurement methods are defined for specified attributes. Where possible, these definitions are by reference to an IEC standard – otherwise the test or measurement method is outlined in the relevant sectional, family and/or detail specification.

Annex A gives examples of fibre optic sensors to better illustrate the classification scheme. The examples given are illustrative only and are not limitative, nor do they constitute a recommendation or endorsement of a particular transduction principle.

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 60050, *International Electrotechnical Vocabulary*

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60068-1 *Environmental testing – Part 1: General and guidance*

IEC 60068-2-1, *Environmental testing – Part 2-1: Tests – Test A: Cold*

IEC 60068-2-2, *Environmental testing – Part 2-2: Tests – Test B: Dry heat*

IEC 60068-2-5, *Environmental testing – Part 2-5: Tests – Test Sa: Simulated solar radiation at ground level and guidance for solar radiation testing*

IEC 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-10, *Environmental testing – Part 2-10: Tests – Test J and guidance: Mould growth*

IEC 60068-2-11, *Basic environmental testing procedures – Part 2-11: Tests – Test Ka: Salt mist*

IEC 60068-2-13, *Basic environmental testing procedures – Part 2-13: Tests – Test M: Low air pressure*

IEC 60068-2-14, *Environmental testing – Part 2-14: Tests – Test N: Change of temperature*

IEC 60068-2-27, *Environmental testing – Part 2-27: Tests – Test Ea and guidance: Shock*

IEC 60068-2-30, *Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle)*

IEC 60068-2-42, *Environmental testing – Part 2-42: Tests – Test Kc: Sulphur dioxide test for contacts and connections*

IEC 60068-2-43, *Environmental testing – Part 2-43: Tests – Test Kd: Hydrogen sulphide test for contacts and connections*

IEC 60068-2-78*, Environmental testing – Part 2-78: Tests – Cab: Damp heat, steady state*

IEC 60079-28, *Explosive atmospheres – Part 28: Protection of equipment and transmission systems using optical radiation*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60695-11-5, *Fire hazard testing – Part 11-5: Test flames – Needle-flame test method – Apparatus, confirmatory test arrangement and guidance*

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

IEC 60793-1-54, *Optical fibres – Part 1-54: Measurement methods and test procedures - Gamma irradiation*

IEC 60793-2, *Optical fibres – Part 2: Product specifications – General*

IEC 60794-1-1, *Optical fibre cables – Part 1: Generic specification – General*

IEC 60794-1-2, *Optical fibre cables – Part 1-2: Generic specification – Basic optical cable test procedures*

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 60874-1, *Fibre optic interconnecting devices and passive components – Connectors for optical fibres and cables – Part 1: Generic specification*

IEC 61000-4-2, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-4, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test*

IEC 61000-4-5, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61300 (all parts), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures*

IEC 61300-2-18, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-18: Tests – Dry heat – High temperature endurance*

IEC 61300-2-22, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-22: Tests – Change of temperature*

IEC 61300-2-34, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-34: Tests – Resistance to solvents and contaminating fluids of interconnecting components and closures*

IEC 61300-2-46, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-46: Tests – Damp heat, cyclic*

IEC 61300-3-35, *Fibre optic interconnecting devices and passive components –Basic test and measurement procedures – Part 3-35: Examinations and measurements – Fibre optic connector endface visual and automated inspection*

IEC 61753 (all parts), *Fibre optic interconnecting devices and passive components performance standard*

IEC/TR 61931, *Fibre optic – Terminology*

IEC/TR 62222, *Fire performance of communication cables installed in buildings*

IEC/TR 62283, *Optical fibres – Guidance for nuclear radiation tests*

IEC/TR 62362, *Selection of optical fibre cable specifications relative to mechanical, ingress, climatic or electromagnetic characteristics – Guidance*

IEC/TR 62627-01, *Fibre optic interconnecting devices and passive components – Part 01: Fibre optic connector cleaning methods*

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

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purpose of this International Standard, the definitions of IEC 60050 (IEV), IEC/TR 61931, ISO/IEC Guide 99 (VIM), and the following apply:

3.1
accuracy
quality which characterizes the ability of a measuring instrument [of a fibre optic sensor] to provide an indicated value close to a true value of the measurand

Note 1 to entry: This term is used in the "true value" approach. This is a value that would be obtained by a perfect measurement.

Note 2 to entry: Accuracy is all the better when the indicated value is closer to the corresponding true value.

[SOURCE: IEC 60050-311:2001, 311-06-08, modified]

3.2
analogue signal interface
signal interface which provides analogue output signals in a form directly usable for control or measurement purposes, and which is generally electrical

Note 1 to entry: Output schemes should preferably comply with existing interface standards such as those existing for electrical analogue signals. Output schemes can be, for example, 4-20 mA, 0-20 mA, 0-5V, etc. A fibre optic sensor with a photodetector or other square-law detector, or with integrated signal processing electronics is a representative application example.

3.3
characteristic curve / calibration curve
expression of the relation between indication and corresponding measured quantity value

[SOURCE: ISO/IEC Guide 99]

Note 1 to entry: A characteristic curve / calibration curve expresses a one-to-one relation that does not supply a complete measurement result as it bears no information about the measurement uncertainty.

3.4
communication interface
digital interface of a fibre optic sensor which provides digital output signals in a form directly usable for control or measurement purposes, or which enables digital communication with other digital divices (e.g. personal computer)

Note 1 to entry: It is usually designed to a specific standard (e.g. Universal Serial Interface Bus USB, RS-232) and used for transmitting control and measurement data.

3.5
distributed fibre optic sensor
fibre optic sensor which provides a spatially resolved measurement of a measurand over an extended region by means of a continuous sensing element

3.6
drift
change in the metrological characteristics of a measuring instrument [and /or fibre optic sensor], generally slow, continuous, not necessarily in the same direction and not related to a change in the measurand

3.7
durability
ability of a fibre optic sensor to perform a required function under defined conditions of use and maintenance, until a limiting state is reached

Note 1 to entry: A limiting state of an item may be characterized by the end of the useful life, unsuitability for any economic or technological reasons or other relevant factors.

3.8
extrinsic fibre optic sensor
fibre optic sensor in which the characteristics of the light are affected externally to the optical fibre(s) by the measurand

3.9
fibre optic sensor
part of a measuring instrument, or measuring chain, which is directly affected by the measurand and which generates a change in the optical characteristics of an optical fibre related to the value of the measurand. The optical fibre itself acts as the sensing element or it includes an optical or optically powered sensing element and may include one or more of the following (see Figures 1, 2, and 3):

– optical fibre lead;
– signal conditioning.

3.10
gauge length / measurement basis
length of the parallel portion of the measured object over which the fibre optic sensor gathers information

[SOURCE: COST Guideline for Use of Fibre Optic Sensors]

Note 1 to entry: For example, if the sensor is only anchored at two fixed points L cm apart, then the gauge length is L. On the other hand, if a sensor of length l is continuously-fixed in or to a measured object of length L, then the actual gauge length depends on the method of attachment to the measured object and is a function of the mechanical properties of both the sensor and its surrounding; it is generally longer than l but shorter than L.

Note 2 to entry: If a user wants to achieve a pre-determined gauge length, he must be very careful in selecting the procedure by which the sensor is anchored/attached/embedded. In case of continuously-fixed sensors, the fixing length must exceed the defined gauge length by a few tens of fibre diameter to avoid shear-lag problems at the edges. In the specific case of fracture or cracks within the gauge length of the sample, the final gauge length must be calculated then from the gauge length at fracture by subtracting from the latter the elastic portion of the elongation.

3.11
influence quantity
quantity that, in a direct measurement, does not affect the quantity that is actually measured, but affects the relation between the indication and the measurement result

[SOURCE: ISO/IEC Guide 99]

3.12
integrating fibre optic sensor

fibre optic sensor which provides a measurement result of a measurand over an extended region by means of a continuous sensing element of a defined length. The measurand is not spatially resolved but is integrated or summed over the length of the sensing element.

3.13
intrinsic fibre optic sensor
fibre optic sensor whose sensing element consists of one or more optical fibre(s) in which one or more characteristics like intensity, phase, polarization, spectrum, wavelength or transit time of light depend on the measurand

Note 1 to entry: There are a lot of fibre optic sensors where the sensing principle is based on a change in coating characteristics only (e.g. chemical or RH sensors) or on an interaction between core and cladding (e.g. bending sensor). They can be defined as indirect intrinsic fibre optic sensors. Direct intrinsic fibre optic sensors are defined by a direct change of the fibre core characteristics (e.g. Brillouin, Raman or Rayleigh scattering based sensors).

3.14
instrumental measurement uncertainty
component of measurement uncertainty arising from a measuring instrument or measuring system in use

Note 1 to entry: Instrumental measurement uncertainty is obtained through calibration of a measuring instrument or measuring system, except for a primary measurement standard for which other means are used.

Note 2 to entry: Instrumental uncertainty is used in a Type B evaluation of measurement uncertainty according to ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*.

3.15
limiting operating condition / limiting values for operation
extreme operating condition that a measuring instrument or measuring system or a sensing element [or a fibre optic sensor] is required to withstand without damage, and without degradation of specified metrological properties, when it is subsequently operated under its rated operating conditions

[SOURCE: ISO/IEC Guide 99]

Note 1 to entry: Limiting conditions for storage, transport or operation can differ.

Note 2 to entry: Limiting conditions can include limiting values of a quantity being measured and of any influence quantity.

Note 3 to entry: The limiting values can depend on the duration of their application.

3.16
measurement precision
closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions

[SOURCE: ISO/IEC Guide 99]

Note 1 to entry: Measurement precision is usually expressed numerically by measures of imprecision, such as standard deviation, variance, or coefficient of variation under the specified conditions of measurement.

Note 2 to entry: The ‘specified conditions’ can be, for example, repeatability conditions of measurement, intermediate precision conditions of measurement or reproducibility conditions of measurement.

Note 3 to entry: Measurement precision is used to define measurement repeatability, intermediate measurement precision, and measurement reproducibility.

Note 4 to entry: Sometimes “measurement precision” is erroneously used to mean measurement accuracy.

3.17
measuring interval / measuring range
set of values of quantities of the same kind that can be measured by a given measuring instrument or measuring system [or fibre optic sensor] with specified instrumental uncertainty, under defined conditions

[SOURCE: ISO/IEC Guide 99]

3.18
multiple point fibre optic sensor
fibre optic sensor consisting of a number of single point sensors which enables a spatially resolved measurement of a measurand over an extended region at discrete locations

3.19
optical or optically powered sensing element
device which accepts information in the form of a physical quantity and converts it to information in the form of an optical quantity, according to a definite law

3.20
optical fibre
filament-shaped waveguide made of dielectric materials for guiding optical waves

[SOURCE: IEC 60050-151:2001, 151-12-35]

For the purpose of this International Standard, the general specifications for optical fibres of IEC 60793-2 apply.

Note 1 to entry: Fibre optic sensors based on planar or micro-structured waveguides, or photonic crystal fibres or multi-core fibres are under consideration and not yet part of this standard.

3.21
optical fibre lead(s)
optical fibre line(s) which connect the sensing element to the optical source and to the optical receiver

3.22
optical interface
arbitrary point at which the effect of the measurand on the sensing element is optically defined

Note 1 to enrty: The optical interface represents the raw optical signal for subsequent processing by the user. Typical attributes for this type of interface would be the wavelength, state of polarization, optical power, and so on. More detailed specifications would include fibre-optic connector style, optical fibre type, etc.

3.23
optical receiver
device which receives the light affected by the measurand and converts it into a quantity, generally electric, according to a predetermined law. It may contain one or more photo detectors, signal conditioners and communication interfaces

3.24
optical source
device which supplies the optical energy required to allow the interaction between the sensing element and the measurand. It contains, as a minimum, a luminous source and it may contain signal conditioning. When the optical energy is generated by the phenomenon sensed, no optical source is required

3.25
rated operating condition
operating condition that must be fulfilled during measurement in order that a measuring instrument or measuring system [or fibre optic sensor] perform as designed

[SOURCE: ISO/IEC Guide 99]

Note 1 to entry: Rated operating conditions generally specify intervals of values for a quantity being measured and for any influence quantity.

3.26
resolution
smallest change in a quantity being measured that causes a perceptible change in the corresponding indication

[SOURCE: ISO/IEC Guide 99]

Note 1 to entry: Resolution can depend on, for example, noise (internal or external) or friction. It may also depend on the value of a quantity being measured.

3.27
sensitivity
quotient of the change in an indication of a measuring system [or a fibre optic sensor] and the corresponding change in a value of a quantity being measured

[SOURCE: ISO/IEC Guide 99]

Note 1 to entry: Sensitivity of a measuring system can depend on the value of the quantity being measured.

Note 2 to entry: The change considered in a value of a quantity being measured must be large compared with the resolution.

3.28
signal interface
arbitrary point at which the effect of the measurand is present in a form directly usable for control or measurement purposes. The optical interface(s) and the signal interface(s) can in some cases coincide

3.29
single point fibre optic sensor
fibre optice sensor consisting of one discrete sensing element which generates a signal related to the value of the measurand

3.30
spatial resolution
measure of the ability of a distributed fibre optic sensor to distinguish spatial indications of the measurand

Note 1 to entry: Measurand resolution (e.g. temperature or strain), spatial resolution, distance range and acquisition time are inter-related. The signal processing has additional influence.

3.31
stability
ability of a measuring instrument [and /or fibre optic sensor] to keep its [metrological] performance characteristics within a specified range during a specified time interval, all other conditions being the same

[SOURCE: IEC 60050:2001, 311-06-12, modified]

3.32
step response time
duration between the instant when the measurand (or quantity supplied) is subjected to a specified abrupt change and the instant when the indication (or quantity supplied) reaches, and remains within specified limits of, its final steady-state value

Note 1 to entry: This definition is the one conventionally used for measuring instruments. Other definitions exist.

[SOURCE: IEC 60050-311:2001, 311-06-04]

3.33
variation due to an influence quantity / cross sensitivity
difference in indication for a given measured quantity value when an influence quantity assumes successively two different quantity values [e.g. while measuring a strain a temperature change may appear as a strain change.

[SOURCE: ISO/IEC Guide 99]

Figure 1 shows fibre optic sensor configuration with a passive sensing element and separate fibre leads for optical input and output.

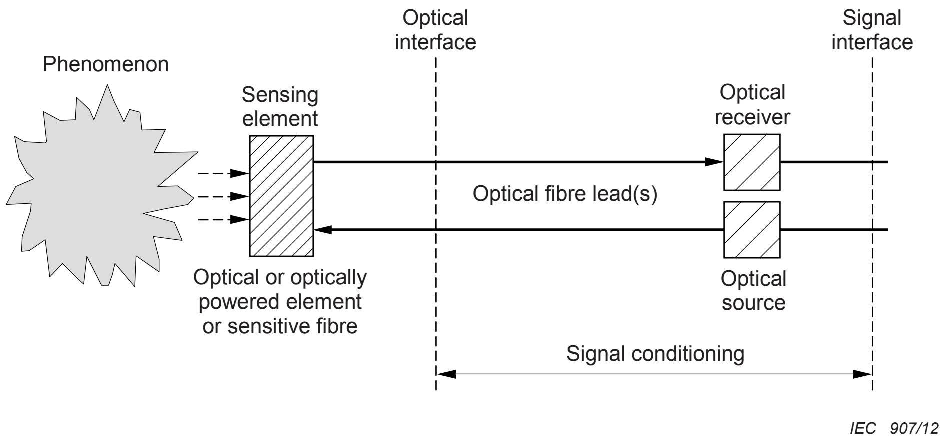

Figure 1 – Fibre optic sensor configuration with a passive sensing element and separate fibre leads for optical input and output

Figure 2 shows fibre optic sensor configuration with an active sensing.

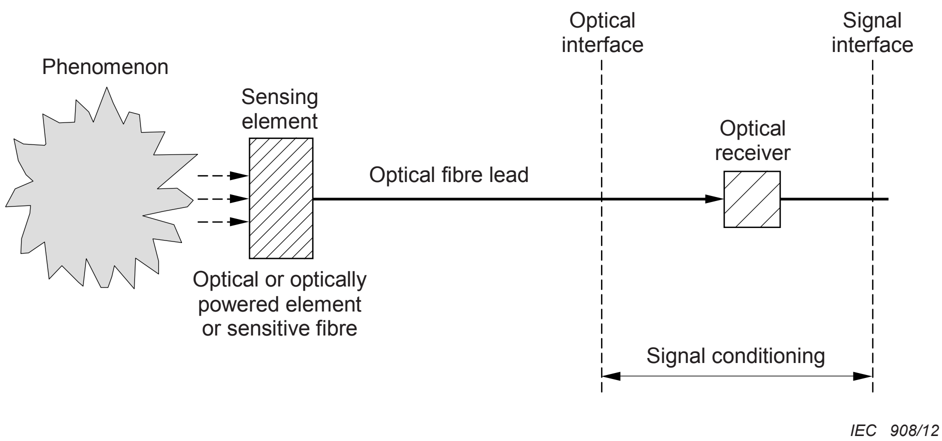

Figure 2 – Fibre optic sensor configuration with an active sensing

Figure 3 shows fibre optic sensor configuration with a passive sensing element and one fibre lead for optical input and output; signal separation is realized by a Y-splitter.

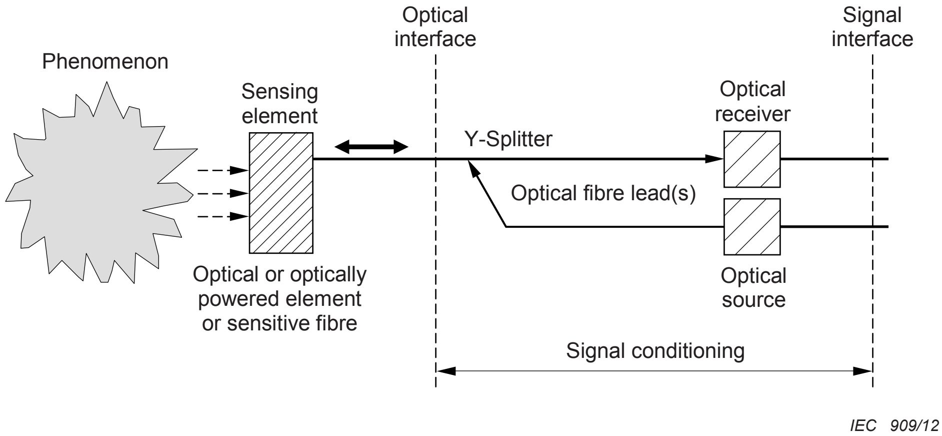

Figure 3 – Fibre optic sensor configuration with a passive sensing element and one fibre lead for optical input and output; signal separation is realized by a Y-splitter

4 Quality assurance

Compliance with this International Standard does not guarantee the manufacturing consistency of each produced fibre optic sensor. This should be maintained using a recognised quality assurance programme.

When the customer wishes to specify acceptance tests or other quality assurance procedures, it is essential that an agreement be reached between the supplier and the customer at the time of ordering.

The present generic specification provides the normative references, definitions, test and measurement procedures, and classification criteria applicable to fibre optic sensors in general. Because of the wide variety of fibre optic sensor classes, the sectional specifications shall prescribe those tests which are applicable to each particular class of fibre optic sensors. The family and/or detail specifications shall describe which of the tests prescribed in the relevant sectional specifications are applicable to a particular style or variant of a fibre optic sensor.

The relevant sectional, family and/or detail specifications shall also specify which of the tests and performance levels are applicable to the different elements of the fibre optic sensor, such as the optical source, the optical receiver, the sensing element and the optical fibre leads.

5 Test and measurement procedures

5.1 General

The purpose of this clause is to introduce general test and measuring methods applicable to fibre optic sensors. These tests and measurements are intended to address the interaction of the various components of the fibre optic sensor as they function to translate the specified measurand to the specified output at the optical or signal interface.

There are three categories of tests and measurements:

– parameter measurements;
– performance measurements;
– compliance tests.

5.2 Standard conditions for testing

All discrete components (optical source, optical detector, optical fibre couplers, optical fibres, etc.) shall be tested in accordance with applicable specifications prior to assembly of the sensor. All components shall then be assembled and packaged in accordance with the family and/or detail specifications and instructions for use prior to testing the sensor in accordance with this specification.

Tests shall be carried out under standard atmospheric conditions for testing as specified in IEC 60068-1. The atmospheric conditions need to be controlled within some range to ensure proper correlation of data obtained from measurements and tests conducted in various facilities. Before measurements are made, the sensors shall be preconditioned under standard atmospheric conditions for testing, for a time sufficient to allow each element or the entire sensor to reach thermal stability. The above requirements shall apply, unless otherwise specified in the sectional, family and/or detail specifications.

When “mounting” is specified in a test, the specimen shall be securely mounted to a rigid support of suitable material, of dimensions and contour such that the specimen is rigidly and completely supported as it would be in use. For free or fixed specimens, the appropriate mounting fixtures shall be specified in the relevant sectional, family and/or detail specifications.

Recovery conditions for the interval following a conditioning test shall be in accordance with the relevant IEC publications unless otherwise specified in the sectional, family and/or detail specifications.

5.3 Test and measurement equipment requirements

Test and measurement equipment, including required power supplies and the source of the measurand (tuneable within the range specified in the family and/or detail specification), shall be calibrated and adjusted in accordance with the manufacturer instructions before use, in order to minimize measurement uncertainty. Critical equipment shall be traceable to the International System of Units (SI).

The stability and measurement uncertainty of the test and measurement equipment shall be substantially better than the specified accuracy of the fibre optic sensor under test.

5.4 Visual inspection

The marking of each sensor shall be in accordance with Clause 7 of this generic specification, and shall be inspected for legibility and completeness.

Visual inspection shall verify that all elements required in the family and/or detail specifications are included in the sensor and connected as described in the family and/or detail specifications to ensure proper functioning. Visual inspection shall also verify that no elements evidence any physical damage or imperfection that could impair the functioning or lifetime of the sensor.

5.5 Dimensions

Dimensional measurements shall be performed to ensure that the sensor conforms to all critical dimensions and weight as specified in the relevant sectional, family and/or detail specifications.

5.6 Metrological properties

5.6.1 General

The purpose of the tests concerning metrological properties is to characterize the effect of the measurand and disturbing influence quantities on the sensor output at the optical or signal interface or the indication of the complete measuring system. This set of tests shall be carried out under reference conditions as described in the relevant sectional, family and/or detail specifications.

In this generic specification relevant parameters which characterize metrological properties will be outlined only. Appropriate sensor specific test procedures and measurand values used shall be specified in the relevant sectional, family and/or detail specifications.

5.6.2 Metrological parameters

At a minimum the following metrological performance specifications and parameters shall be determined in order to characterize the metrological properties of a fibre optic sensor or measuring system (cited in alphabetic order):

- accuracy;
- durability;
- instrumental measurement uncertainty;
- limiting operating condition / limiting values for operation;
- measurement precision;
- measuring interval / measuring range;
- resolution / spatial resolution (if appropriate);
- sensitivity;
- stability / drift;
- step response time (if appropriate);
- variation due to an influence quantity / cross sensitivity.

5.7 Optical tests

5.7.1 General

In sensor configurations which permit optical testing, the following parameters may be included in the sectional, family and/or detail specifications.

5.7.2 Optical power

The optical power shall be measured with a traceable calibrated optical power meter.

5.7.3 Nominal wavelength and appropriate spectral characteristics

The nominal wavelength of a laser shall be measured with a traceable calibrated optical wave meter. The nominal wavelength of a broadband light source or spectral response of a fiber optic sensor shall be measured with a traceable calibrated optical spectrum analyzer.

5.7.4 State of polarization

The state of polarization shall be measured with a traceable calibrated polarimeter.

5.7.5 Fibre connector performance

For the purpose of this International Standard, the general specifications for fibre optic connectors of IEC 61753 (all parts) apply. Connector end faces shall be inspected in accordance with IEC 61300-3-35 and if required cleaned in accordance with IEC/TR 62627-01.

5.8 Electrical tests

5.8.1 General

The purpose of electrical tests is to verify that the fibre optic sensor has been designed and fabricated in accordance with safe and established design practices with regard to electrical equipment requirements so that the fibre optic sensor can be operated safely and reliably. The list of parameters given in 5.8.2 may be used as a guide for determining which procedures are appropriate for those fibre optic sensors which include electrical components or circuits.

5.8.2 Parameters and test procedures

Parameter	*Test procedure*
Insulation resistance	IEC 60060-1
Dielectric withstand at industrial frequency	IEC 60060-1
Lightning impulse	IEC 60060-1
Voltage stress	See 5.8.3
Fast transients	IEC 61000-4-4
Impulse sparkover voltage	IEC 61000-4-5
Impulse discharge current	IEC 61000-4-5
Electrostatic discharge	IEC 61000-4-2
Electromagnetic field	IEC 61000-4-3

5.8.3 Voltage stress

– Influence of the level of voltage supply:

  The equipment is subjected to variations of the voltage supply U between U_{min} and U_{max} as specified in the relevant family and/or detail specifications.

– Slow variation of voltage supply:

  The equipment installed according to the instructions given in the relevant family and/or detail specifications is powered by its rated voltage. The level of the voltage is decreased from rated voltage to 0 V, then increased from 0 V to rated voltage, as specified in the relevant family and/or detail specifications.

– Influence of frequency:

  As required by the relevant family and/or detail specifications.

– Influence of a micro-cut of supply voltage:

  As required by the relevant family and/or detail specifications.

– Third harmonic:

  As required by the relevant family and/or detail specifications.

5.9 Mechanical tests

5.9.1 General

The purpose of mechanical tests is to verify that the fibre optic sensor has been fabricated in accordance with safe and established design practices with regard to mechanical reliability. The list of parameters given in 5.9.2 may be used as a guide for determining which procedures are appropriate for fibre optic sensors. For industrial premises installations parameters for mechanical testing may be used according to environments defined by the Mechanical, Ingress, Climatic and Chemical, and Electromechanical (MICE) classification. For supplemental guidance see IEC/TR 62362 and ISO/IEC TR 29106.

5.9.2 Parameters and test procedures

Parameters	*Test procedure*
Vibration	IEC 60068-2-6 and IEC 61300-2-1
Shock and Bump	IEC 60068-2-27 and IEC 61300-2-9
Bending of fibre leads	IEC 60794-1-1 and IEC 60794-1-2
Twisting of fibre leads	IEC 60794-1-1 and IEC 60794-1-2
Crushing of fibre leads	IEC 60794-1-1 and IEC 60794-1-2
Tensile strength of fibre leads	IEC 60794-1-1 and IEC 60794-1-2
Fibre connector	IEC 60874-1 and IEC 61300 series
Macrobending of optical fibre	IEC 60793-1-1
Tensile strength of optical fibre	IEC 60793-1-1
Fibre and coating geometry	IEC 60793-1-1
Coating strippability	IEC 60793-1-1

5.10 Climatic and environmental tests

5.10.1 General

Climatic and environmental tests are designed to verify that the influence of the specified climatic and environmental conditions on the metrological features of the system is in accordance with the family and/or detail specifications. During these tests, the value of the measurand shall be in accordance with the family and/or detail specifications in magnitude and stability. The list of parameters given in 5.10.2 may be used as a guide for determining which procedures are appropriate for fibre optic sensors. For industrial premises installations parameters for climatic and environmental testing may be used according to environments defined by the Mechanical, Ingress, Climatic and Chemical, and Electromechanical (MICE) classification. For supplemental guidance see IEC/TR 62362 and ISO/IEC TR 29106.

In common with other components the climatic category of a fibre optic sensor shall be expressed in the form prescribed in IEC 60068-1. The minimum test procedures for establishing the performance of a fibre optic sensor within a given climatic category are as follows:

a) cold;

b) dry heat;

c) damp heat, steady state;

5.10.2 Parameters and test procedures

Parameter	*Test procedure*
Cold	IEC 60068-2-1 (Ab/Ad)
Dry heat	IEC 60068-11-5 (Bb/Bd) and IEC 61300-2-18
Rapid change of temperature	IEC 60068-2-14 (Na/Nb) and IEC 61300-2-22
Damp heat, steady state	IEC 60068-2-78
Damp heat, cyclic test	IEC 60068-2-30
Corrosive atmosphere	IEC 60068-2-11 and IEC 61300-2-46
Sealing	IEC 60529
Dust	IEC 60529
Industrial atmosphere	IEC 60068-2-42 and IEC 60068-2-43
Flammability and fire resistance	IEC 60695-2-2 and IEC/TR 62222
Mould growth	IEC 60068-2-10
Low air pressure	IEC 60068-2-13

Solar radiation	IEC 60068-2-5
Nuclear radiation	IEC/TR 62283 and IEC 60793-1-54
Susceptibility to ambient light	See 5.11
Biological attack	under consideration

NOTE When fibre optic sensors are used in e. g. offshore or sewage system environment, microbiological attacks and bacteriological layers can damage or influence the sensor function.

5.11 Susceptibility to ambient light

Measurement of susceptibility to ambient light is intended to establish that ambient light is not coupled to the optical fibres or to the optical receiver in a manner that adversely affects the fibre optic sensor performance. The wavelength, modulation, intensity and direction of a light source used to simulate ambient lighting shall be specified in the relevant sectional, family and/or detail specifications if applicable.

5.12 Resistance to solvents and contaminating fluids

A list of fluids to which the different elements of the fibre optic sensor shall be resistant shall be specified in the relevant sectional, family and/or detail specifications. For industrial premises installations parameters for chemical resistance testing may be used according to environments defined by the Mechanical, Ingress, Climatic and Chemical, and Electromechanical (MICE) classification. For supplemental guidance see IEC/TR 62362 and ISO/IEC TR 29106. For connectors the parameters of IEC 61300-2-34 may also be used.

6 Classification

6.1 General

The purpose of this classification scheme is to allow for the development of sectional, family and/or detail specifications, based on the commonality of quality assurance procedures at the optical or the signal interface level.

For this purpose, fibre optic sensors are classified according to the following four types of criteria:

– measurand;
– transduction principle;
– spatial distribution;
– interface level;

6.2 Measurand

The measurand designates the physical or electrical quantity, property, or condition that is to be measured by the fibre optic sensor.

The following is not intended to be an all-inclusive list, but a sampling of measurands for fibre optic sensors. Examples given in Annex A are illustrative and shall not be considered as limitative, nor do they constitute a recommendation or endorsement of a particular transduction principle.

6.2.1 Presence/absence of objects or features

Limit sensor (button, lever, key): A fibre optic limit sensor detects motion occurring beyond a predetermined point.

Level: A fibre optic level sensor detects when a solid or liquid rises or falls beyond a set position.

Proximity: A fibre optic proximity sensor detects the presence or absence of a given object.

Photo-interruption: A fibre optic photo-interruption sensor detects the crossing of a boundary by an object or a body.

6.2.2 Position

Linear position: A fibre optic linear position sensor determines the absolute or relative location of an object along a line within a certain bounded region.

A differential position sensor determines the relative position of two or more objects.

Angular position: A fibre optic angular position sensor determines the absolute or relative position of an object rotating about an axis.

Proximity: A fibre optic proximity sensor determines the relative closeness of an object to a predefined location.

Zone (area): A fibre optic zone sensor may be considered as a multi-dimensional extension of the linear position sensor. A two-dimensional array of sensing points or a converging/diverging set of sensor stimuli would constitute a zone sensor.

Dimensional: fibre optic dimensional sensors can be used to determine the dimensions of an object.

6.2.3 Rate of positional change

Linear speed or velocity: A fibre optic linear speed sensor determines the rate of movement of an object.

Rotational speed or velocity: A fibre optic rotational speed sensor determines the angular velocity of a rotating object.

Gyroscope: A fibre optic gyroscope is an inertial sensor which determines the rate of rotation or integrated degree of rotation with respect to a fixed inertial frame, defined about an input axis.

Linear acceleration: A fibre optic linear acceleration sensor determines the rate of change of the velocity of an object along a given vector.

Rotational acceleration: A fibre optic rotational acceleration sensor determines the rate of increase or decrease in angular velocity of a rotating object.

6.2.4 Flow

Fibre optic sensors can be used to determine the rate of flow or the amount of a moving fluid in a conduit, with several techniques in use.

6.2.5 Temperature

Point temperature sensors and distributed temperature sensors measuring multiple points along a fibre are in use.

6.2.6 Force x directional vector

Seismic: A fibre optic seismic sensor determines vibrational motion of the ground on a planet or other celestial object.

Vibration: A fibre optic vibration sensor determines the magnitude of force experienced by a body undergoing periodic motion in alternately opposite directions.

Torque: A fibre optic torque sensor determines the rotational force applied at a specific perpendicular distance to the axis of rotation of an object.

Weight: A fibre optic weight sensor determines the force of gravity acting on a body of a given mass.

6.2.7 Force per area

Acoustic: A fibre optic acoustic sensor determines the time-varying pressure caused by acoustic waves.

Pressure: A fibre optic pressure sensor determines the pressure of a gas or liquid.

6.2.8 Strain

Fibre optic sensors can be used to determine a finite change in the length of a material (strain) resulting from tension or compression, with several techniques in use.

6.2.9 Electromagnetic quantities

Magnetic field: A fibre optic magnetic field sensor determines magnetic fields, with several techniques in use.

Electrical current: A fibre optic current sensor is a special type of magnetic field sensor in which the integral of the magnetic field along some path around a conductor is measured. Because the integral of the magnetic field around a conductor is equal to the current flowing through the conductor (Ampere's law) the result is a sensor that responds only to the current in the conductor and not to other currents or magnetic fields in the vicinity.

Electric field: A fibre optic electric field sensor determines electric fields, with several techniques in use.

Voltage: A fibre optic voltage sensor is an electric field sensor in which electrodes are attached to the sensor in such a way that the electric field is applied to the sensing element in a defined geometry.

Electromagnetic radiation: Fibre optic sensors can be designed to detect or characterize electromagnetic radiation such as microwaves, light waves, etc.

6.2.10 Ionizing and nuclear radiation

This type of fibre optic sensors can be used to detect α, β, γ and other ionizing radiation.

6.2.11 Other physical properties of materials

Material refractive index: A fibre optic refractive index sensor determines refractive indices in mixtures of fluids.

Density: A fibre optic density sensor determines the mass density (g/cm^3) of particulate matter.

Viscosity: A fibre optic viscosity sensor determines the resistance to flow of a given fluid.

Damage: Gross structural damage, structural integrity and incipient damage of military hardware, civil engineering and architecture can be detected with fibre optic sensors.

6.2.12 Composition and specific chemical quantities

Chemical: Fibre optic sensors can be used to measure a single chemical quantity or to examine a material or mixture. Qualitative and quantitative analyses for chemical species contaminants, and reaction process control are the main uses of this type of sensor.

6.2.13 Particulates

Count: A fibre optic particulate sensor determines the size distribution and frequency of airborne or liquid-borne particulate matter.

Atomic: Fibre optic sensors can be used to detect contaminated microscopic and macroscopic particulate matter that has become activated or otherwise radioactive.

Turbidity: A fibre optic turbidity sensor determines the cloudiness or opaqueness of a given fluid.

6.2.14 Imaging

A fibre optic image sensor can be used to transfer an image.

6.3 Transduction principle

The transduction principle describes the way in which the optical characteristics of light are affected by the measurand. It can be described by the transfer function from the measurand to the optical guided wave.

6.3.1 Active generation of light

The measurand directly creates optical energy, whose characteristics can be analyzed to extract an estimation of the measurand. Examples of active generation of light include blackbody radiation, Cerenkov radiation, electric arc.

6.3.2 Atom-field interaction

An optical probe at a specific wavelength or wavelengths is used to examine the desired measurand. The characteristics of the sensed material somehow modify the probe light, which is subsequently detected at one or more wavelengths or frequencies. Examples of atom-field interaction include spectrally resolved absorption, fluorescence, spectroscopy, Doppler and nonlinear effects.

6.3.3 Coherence modulation

Fibre optic sensors can use coherence modulation in conjunction with broadband light interferometric techniques to characterize measurands. Coherence modulation is often used to resolve a measurement spatially. Some white-light interferometers fall under this type of sensors.

6.3.4 Intensity modulation

Fibre optic sensors employing intensity modulation have a transfer function whose output is expressed as an intensity. Examples of intensity modulation include attenuation, coupling effects, interruption, microbending, and reflectivity.

6.3.5 Optical spectrum modulation

Fibre optic sensors can use optical spectrum modulation. Examples of optical spectrum modulation include Brillouin scattering, fluorescence, broadband light interferometry, Doppler effect, wavelength of the reflected light from fibre gratings.

6.3.6 Phase modulation

Fibre optic sensors can use phase modulation in conjunction with interferometric techniques to characterize various measurands. Electro- or magneto-strictive coatings, acoustical energy, linear strain, Sagnac shift, Faraday effect and refractive index can all be used in phase-modulated sensors.

6.3.7 Polarization modulation

The state-of-polarization of optical energy can be modified by a measurand; rotation and retardance are common phenomena. These mechanisms occur via the elasto-optic effect, optical activity or other transduction principles.

6.4 Spatial distribution

The spatial distribution describes the extension and resolution capabilities of the fibre optic sensor. It is distinguished between single point, multiple point, integrating, and distributed sensor types (see Clause 3).

6.5 Interface level

The interface level is defined by the level of conditioning at which the output signal is available to the user. At this interface like optical, analogue signal, and communication interface (see Clause 3), both the sensor inputs and outputs shall be specified. Specifying these interfaces is necessary to enable the user to exploit the information provided by the sensor and to ensure interoperability between different products.

7 Marking, labelling, packaging

7.1 Marking of component

Each fibre optic sensor shall be legibly and durably marked, where space permits, with:

– device identification;
– manufacturer's identity mark;
– manufacturing date code (year/production lot code);
– metre marking for distributed sensor cables;
– laser radiation warning information or warning label if required.

7.2 Marking of sealed package

Each sensor package shall be marked with the following:

– IEC type designation;
– any additional marking required by the sectional, family and/or detail specifications.

When required by the sectional, family and/or detail specifications, the package shall also include instructions for assembling the sensor(s) and the description of any special tools or materials, as necessary.

Where applicable, individual unit packages (within the sealed package) shall be marked with the reference number of the certified record of released lots, the manufacturer's factory identity code, and the component identification.

8 IEC type designation

The fibre optic sensors to which this standard applies shall be designated by the letters IEC followed by the number of the relevant family or detail specification.

9 Safety aspects

9.1 General

Fibre optic components and systems may emit hazardous radiation. This can occur at:

- sources;
- transmission systems under the following conditions:
  - installation,
  - service or intentional interruption,
  - failure or unintentional interruption;
- measuring and testing;

9.2 Personal safety

For personal hazard evaluation, precautions and manufacturer's requirements, the relevant document is IEC 60825-1.

9.3 Safety in explosive environment

Any sensor cable and device intended for use in explosive environments must be approved by a certified body according to IEC 60079-28 and marked accordingly.

10 Ordering information

The following ordering information shall be included in purchasing contracts for items complying with this standard:

- IEC type designation;
- any additional information or special requirements.

11 Drawings included in the sectional, family and detail specifications

The essential purpose of the drawings is to ensure mechanical interchangeability. They are not intended to restrict details of construction which do not affect interchangeability, nor are they to be used as manufacturing drawings. Equipment designers shall work to the limits stated and not to dimensions of individual specimens.

Annex A
(informative)

Examples of fibre optic sensors

A.1 General

The examples given below illustrate how fibre optic sensors can measure the various measurands listed in 6.1. The classification in this annex closely follows that of 6.2. The examples given are illustrative and shall not be considered as limitative, nor do they constitute a recommendation or endorsement of a particular transduction principle.

A.2 Presence/absence of objects or features

A.2.1 Limit sensor (button, lever, key)

A fibre optic limit sensor detects motion occurring beyond a predetermined point. The function of this device is typically to initiate a change of action when the predetermined point has been reached. An example of a fibre optic limit sensor is one which detects the breaking of a light beam, for example by a linear translation mechanism passing a reflective head. The limit sensor can then close (or open) a switch to stop the motion in order to avoid damaging the drive mechanism. This type of sensor is also useful for synchronization or home sensing for rotational or linear motion systems.

A.2.2 Level

A fibre optic level sensor detects when a solid or liquid rises or falls beyond a set position. For example, an optical fibre experiences a 4 % Fresnel reflection at the polished endface exposed to air, due to an index of refraction mismatch. When a liquid reaches this fibre end, the reflection decreases due to improved refractive index matching. The sensor can activate an alarm indicating that the liquid has risen or fallen, activate a valve to prevent damage or control processing.

A.2.3 Proximity

Fibre optic proximity sensors typically utilize reflection, infrared emission/ reflection, or pressure principles to perform this detection without the necessity for direct physical contact. A typical fibre optic proximity sensor can be used under a carpet to detect the presence of people for security purposes. This sensor might, for example, employ microbending to respond to pressure or vibrational stimuli.

A.2.4 Photo-interruption

A photo-interruption sensor is a device emitting light which typically crosses a boundary such as a doorway. This beam of light is either detected at the opposite side of the boundary or reflected back to a detecting element on the emitting side. An object reflecting or interrupting the light will cause the photo-interruption sensor to trigger an alarm or relay. A fibre optic photo-interruption sensor may be used in applications such as safety mechanisms, counting, and access control.

A.3 Position

A.3.1 Linear position

Fibre optic linear position sensors may, for example, consist of an array of optical fibres placed in a parallel fashion. The object(s) to be detected would pass in front of this array and alter the transmission or reflection of light at the appropriate location from the ends of the fibres. The sensor processing electronics would then derive the proper position of the object within the sensing region from the relative optical amplitude of the signal from each of the fibres. The resolution of the detected position is dependent on the spacing of the sensing points.

A differential position sensor determines the relative position of two or more objects. Such a sensor may be used to help maintain the relative position of two moving objects. Fibre optic differential position sensors may consist of physically separated fibres utilizing reflective or transmissive techniques, or may employ interferometric techniques such as Fabry-Pérot technique.

A.3.2 Angular position

A fibre optic angular position sensor can include multiple sensor fibres arranged in a radial fashion. One application would be the detection of the angular position of a gear or flywheel. A change in light intensity, as a reflective mark or transmissive slot passes a given sensing point, can be decoded to provide relative angular position. Again, the resolution is dependent on the spacing of the sensing points.

A.3.3 Proximity

A proximity sensor using fibre optic technology may have external constrictive coatings on an optical fibre which are acoustically sensitive. An impinging acoustical signal would change the optical signal amplitude in the fibre through a change in the amount of constriction on the fibre.

A.3.4 Zone (area)

Fibre optic zone sensors may be arrays of sensors with sophisticated post processing to deal with the two-dimensional aspects. Phase detection techniques may also be utilized for zone type sensing.

A.3.5 Dimensional

The dimensions of an object may be sensed by using non-contacting fibre optic edge-detection techniques. On-line inspection systems, for example, need to determine the size of objects for sorting or quality purposes. The size of an object may be determined by utilizing an optical fibre array and sensing the change in reflectance or transmission of light in a particular region of the array.

A.4 Rate of positional change

A.4.1 Linear speed or velocity

Fibre optic sensors using Doppler phase shift methods are typical velocity sensors. Such sensors may detect the relative speed of an object without physical contact.

A.4.2 Rotational speed or velocity

A fibre optic rotational speed sensor typically provides an indication of the angular velocity of a rotating wheel, gear or shaft. The speed of rotation of an object may be indicated in revolutions per time period, or radians/degrees per time. A photo-interruption sensor, or chopper, may be utilized to detect the rotational speed or velocity of a given object. Rotational speed sensors are typically found in applications such as tachometers.

A.4.3 Gyroscope

A fibre optic gyroscope consists of a coil of optical fibre (may be polarization preserving) into which light is simultaneously propagating in clockwise and anticlockwise directions. The Sagnac effect, which is a relativistic phenomenon, induces a differential phase shift between clockwise and anticlockwise guided waves in the rotating media. The phase difference of the detected signals is compared and convened into a rate of rotation or an angle of rotation. There are several versions, such as the interferometric fibre optic gyroscope, resonant fibre optic gyroscope, Brillouin fibre optic gyroscope and guided-wave ring-laser gyroscope.

A.4.4 Linear acceleration

Fibre optic accelerometers are normally interferometric in nature. Such sensors may detect acceleration in an indirect manner by taking advantage of the intrinsic strain characteristics of an appropriate optical fibre or a proof mass. Land vehicles and aircraft may utilize such sensors for performance measuring or safety systems.

A.4.5 Rotational acceleration:

A typical fibre optic system would operate with phase differencing techniques. Fibre optic rotational acceleration sensors may be used where weight is a particular concern. Rotational acceleration sensing can be of use in applications such as anti-lock braking on vehicles to prevent skidding. A sudden change in the rate of deceleration can cause the sensor to initiate a correcting control action.

A.5 Flow

A fibre optic flow meter is a device that measures the rate of flow or the amount of a moving fluid in a conduit. The fibre optic flow meter can be identified by its applied theory: for example, velocity, force, vortex shedding, Doppler sensing of particulates. A fibre optic turbine meter would use a fibre to view turbine blade rotation for counting revolutions per minute (RPM). A fibre optic target meter would have a fibre end displaced by a fluid and the microbending of the fibre could be correlated to the fluid flow.

A.6 Temperature

Point techniques are based on fibre Bragg gratings mainly, but also include blackbody-absorbing, phosphorescent-coated, Fabry-Pérot cavity terminated or thermochromic-terminated optical fibres. These fibre optic sensors can trigger a switch at a set point or produce a continuous proportional output. One example of a fibre optic temperature sensor is the blackbody pyrometer. It consists of a blackbody emitting source which responds to incident temperature by emitting into the fibre an optical wavelength(s) of an intensity which is proportional to temperature.

Distributed techniques are mainly based on Raman and Rayleigh scattering. Laser light is continuously scattered in ordinary optical fibre, and the backscattered light is used for calculating temperature profiles along such fibres. Techniques based on spontaneous or stimulated Brillouin and Rayleigh scattering provide another possibility for measuring temperature. However, Brillouin scattering exhibits a cross-sensitivity to strain which must be considered when measuring temperature. For short range applications, Rayleigh scatter interrogated via Optical Frequency Domain Reflectometry (OFDR) provides the highest spatial resolution of the three methods, while Brillouin and Raman are best suited for long range applications.

A.7 Force x directional vector

A.7.1 Seismic

Fibre optic seismic sensing may be done by detecting stress in a given fibre.

A.7.2 Vibration

The electrical isolation, noise immunity and small mass of fibre optic sensors make them well suited to detecting the degree of vibration present in a device or object. Fibre optic vibration sensors may utilize Doppler, optical spectrum-based detection schemes (e.g. fibre Bragg grating), intensity-based or phase-based detection schemes. Piezo-electric optical fibre coatings may be utilized in an intensity-based sensing scheme; another technique would involve a reflective proof mass forming part of a Fabry-Pérot cavity.

A.7.3 Torque

A fibre optic torque sensor may utilize stress as the detecting scheme.

A.7.4 Weight

A change in attenuation due to microbend losses or change in absorption can be used to detect forces. Modal or spectral variations can also be used.

A.8 Force per area

A.8.1 Acoustic

Fibre optic acoustic sensors have been developed in recent years for use as hydrophones for underwater sound detection. These devices are based on fibre optic interferometers. Sound waves striking a coil of fibre in one of two parallel fibres of the interferometer will modulate the length of the sensing fibre slightly. This causes a modulated phase-shift of light in the sensing fibre relative to the reference fibre. The phase modulation can be detected by various heterodyne or homodyne techniques, allowing the sound waveform to be reconstructed.

A.8.2 Pressure

A typical fibre optic pressure sensor for measuring the pressure of a gas or liquid in a container might consist of a reflective diaphragm, one side of which is in contact with the fluid to be measured. An optical fibre (or a bundle of fibres) carries light to and from the diaphragm, which deflects or physically deforms when the pressure of the fluid changes. This deflection in turn changes reflection back into the return fibre lead to the optical receiver.

A physical pressure sensor might consist of a single optical fibre which is held between a pair of saw-toothed mechanical “jaws” at one or more positions along its length. A physical pressure applied to the jaws can mechanically bend the fibre enough to allow some microbending loss to occur, reducing the fibre transmission. This event is sensed by a decrease in the intensity of light at the receiver end of the optical fibre. Another method is to employ a polarimetric sensor via the elasto-optic effect. Such sensors might be used under a doormat as an intruder alarm. Another application might be a physical contact or grip pressure indicator for robot fingers.

A.9 Strain

A fibre optic strain sensor measures a finite change in the length of a material or a structure component resulting from tension or compression. Fibre optic strain sensors are based on different transduction principles depending on the measurement information that the sensor has to gather, e. g local strain changes or distributed strain changes, or the expected time dependence on the measurement signal: static strain, dynamic strain, strain oscillations, acoustic strain waves detection.

Common transduction principles are:

– measurement of intensity variations of the transmitted light e. g. microbend sensor,
– measurement of phase changes and wavelength changes (e. g. Fabry-Pérot sensors, Rayleigh scatter sensors, or fibre Bragg grating sensors,
– time-of-flight measurement, e. g. OFDR-based continuously distributed sensors or OTDR-based multiple point sensors,
– measurement of absorption changes, e. g. partially strain or chemically sensitive sensor areas,
– use of polarimetric effects in fibres, e. g. pressure or bend sensors,
– measurement of non-linear optical signal changes, e. g. Brillouin or Raman scattering based sensors.

An often used fibre strain sensor is based on fibre Bragg grating (FBG) created inside a length of single mode fibre embedded into or attached to the object being monitored. The characteristic wavelength of FBG, usually measured in reflective mode, changes proportionally to fibre strain. Exact proportionality factor between strain and wavelength is influenced by an elasto-optic coefficient of fibre being used. FBG sensors are simultaneously sensitive to temperature changes that have to be considered. FBG sensors are attached to surfaces of structure components or embedded into homogeneous or layered materials, e. g. to determine the extent of structural fatigue. Fibre Bragg grating sensors are used for frequencies up to hundreds of kHz..

High-precision strain measurements are carried out by using interferometric sensors. Fabry-Pérot (FPI) or Michelson interferometric sensors are preferably used. Interferometric sensors are also used for frequencies up to the hundreds of kHz range, e. g. for measurement of acoustic wave signals.

NOTE In order to measure deformations in highly-elastic or curing materials (e. g. epoxy resin, mortar, and concrete), the stiffness of the fibre optic sensor must not initiate stress in the measuring zone. In such cases, a special design of a flexible extrinsic FPI sensor can be used.

Intensity-based sensors are preferably based for short-term static or dynamic strain measurement because of a possible loss of the reference to the initial measurement value (importance of zero-point reference for long-term measurements).

Scanning techniques based on spontaneous or stimulated Brillouin scattering are sensitive to temperature and strain. A laser pulse is launched into the fibre and the frequency shift of the backscattered light caused by spontaneous or stimulated Brillouin scattering (Brillouin frequency shift) is recorded as a function of strain or temperature. Because of their stronger strain sensitivity, these techniques are preferably used for strain measurement along very long optical fibres (distributed strain sensors). However, their cross-sensitivity to temperature can be exploited for combined distributed strain and temperature measurements but must always be considered when only strain is to be measured.

The OFDR interrogation technique, based on swept wavelength interferometry, is sensitive to temperature and strain. A swept laser source and OFDR optical network can be used to measure spectral shifts in the Rayleigh backscatter as a function of length in standard Telecommunications grade fibre. Similar to FBGs, the spectral response of the fibre shifts proportionally with applied strain or temperature. Standard telecom fibre is attached to surfaces or embedded in homogeneous or layered materials. OFDR interrogation of Rayleigh scatter provides millimeter-range spatial resolution over tens to hundreds of meters of standard fibre.

A.10 Electromagnetic quantities

A.10.1 Magnetic field

Fibre optic sensors can be designed to measure magnetic fields using any of several effects. A direct mechanism is the Faraday effect, which is a magnetic field-induced circular birefringence, often described as a rotation of the plane of polarization of linearly polarized light. The Faraday effect can be exploited either in single-mode fibres or bulk materials. It is usually employed in a polarimetric configuration, though interferometric configurations can also be used.

An indirect, intrinsic approach to magnetic field sensors is the use of the magnetostrictive effect in a material attached to a single-mode fibre. Through the elasto-optic effect, the magnetically induced stress changes the propagation characteristics of the fibre which can be detected, usually interferometrically.

A.10.2 Electrical current

Fibre optic current sensors are usually based on the Faraday effect, either in single-mode fibre or bulk optics. An alternate technique uses the magnetostrictive effect; these sensors are interferometric (phase) or polarimetric in nature. Such sensors have advantages due to low mass, electrical isolation and lack of direct interconnection to the primary electrical conductor. A standard use for a fibre optic current sensor is to provide a safe means to monitor current levels in high-voltage power lines.

A.10.3 Electric field

There are no linear electro-optic effects in glass, only the quadratic (Kerr) effect, which is small, and, in principle, higher order effects. Fibre optic electric field sensors thus generally rely either on extrinsic or indirect intrinsic approaches. Extrinsic sensors are typically based on the Pockels effect in a crystalline material. The Pockels effect is an electric field-induced linear birefringence, which can be detected using either polarimetric or interferometric techniques. Sensors using the Pockels effect in both bulk and integrated optic configurations have been demonstrated.

An indirect, intrinsic electric field sensor can be designed using a piezo-electric effect to induce an electric field-dependent stress in an optical fibre. That stress causes a change in the propagation constant of the fibre which can be detected, usually interferometrically.

A.10.4 Voltage

In a sensor based upon the Pockels effect, the electrodes might be applied to the sides of the electro-optic crystal.

A.10.5 Electromagnetic radiation:

A microwave radiation sensor can be designed by using a stress in an optical fibre induced by a temperature rise in a fibre coating sensitive to microwave radiation. Also fibre optic resonators or interferometers can be used to analyze the spectrum of light.

A.11 Ionizing and nuclear radiation

High-energy electromagnetic radiation can produce both loss and fluorescence in glass and other materials. The induced loss is usually associated with a particular type of defect known as a colour centre, which absorbs radiation in specific regions of the visible and near-infrared spectrum. To some degree, the loss is transient. In other cases, it is permanent, thus providing the possibility of total dose sensors.

One source of fluorescence is spontaneous emission from atomic and molecular energy levels excited by the incident radiation. Another source of light is Cerenkov radiation, which occurs when high energy photons scatter electrons within an optical material. If the velocity of these (Compton) electrons exceeds the phase velocity of light in the material, broadband radiation results. Scintillation fibre is an important class of Hadronic detectors for high-energy particle physics. Fluorescence sensors provide a means of measuring the dose rate (power) rather than dose (energy).

A.12 Other physical properties of materials

A.12.1 Material refractive index

A fibre optic refractive index sensor may consist of a miniature Fabry-Pérot type interferometer inserted between two pieces of fibre, with fluid flowing through the optical cavity.

A.12.2 Density

The mass density of particulate matter may be determined by the amount of light transmitted or reflected in the measurement area. Fibre optic sensing of density may be performed using simple intensity-based techniques.

A.12.3 Viscosity

Viscosity is an indication of the resistance to flow of a given fluid. Shearing stress in the direction of fluid flow might be determined by taking advantage of the stress-dependent properties of optical fibre or more simply by detecting a change in the index of refraction or scattering in a fluid.

A.12.4 Damage

Excess loss can be induced in a damage-sensing fibre which is severed at some point along its length if a supporting member fails; optical time domain reflectometry may be used to locate the fault in the structure.

A.13 Composition and specific chemical quantities

A.13.1 Chemical

Chemical presence/detection, concentration, identification, the cure monitoring of adhesives are some of the many applications for chemical sensors. A simple example of a chemical sensor might be a length of optical fibre having a coating over one end which contains a fluorescent material. The fluorescence could be excited by light transmitted down the fibre or by light from an external source. Some of the emitted fluorescence will be trapped in the fibre and guided back to a detector at the other end of the fibre. If the fluorescence of the material is stopped or quenched by, say, a change in the acidity of the surrounding solution (as measured by the concentration of H^+ ions, expressed as the pH), then this device will function as a pH indicator or sensor.

Other fibre optic chemical sensors may use optical fibres merely as a convenient “light pipe” to carry light from a sample to an optical spectrometer for analysis. More advanced types use surface plasmon-polaritron phenomena to evaluate composition at a metal dielectric interface, which is excited by a coupled guided wave. Combustion analysis, toxic gas sensing, relative humidity, environmental, agricultural and biosensors are additional fields of interest for fibre optic chemical sensors.

A.14 Particulates

A.14.1 Count

This can be done by simple interruption, scattering and other techniques.

A.14.2 Atomic

A combination of the fibre optic sensors mentioned in A.13.1 and A.10.5 may be used.

A.14.3 Turbidity

Turbidity may be detected by reflectance sensing techniques. The intensity of light reflected in an optical fibre based sensor system is changed as the level of turbidity in a fluid increases.

A.15 Spatial distribution

A.15.1 Single point

A liquid level sensor which couples light from one fibre to another when the sensor is in contact with air; an electric field sensor which uses polarization state change in a Pockels cell, etc.

A.15.2 Multiple point

A temperature sensor based on temperature-dependent absorption of neodymium-doped short fibre sections spliced at different places along a transmitting fibre, interrogated by optical time domain reflectometry, etc.

Temperature or strain sensors based on fibre Bragg gratings at different wavelengths placed along the fibre, and interrogated by spectral read-out.

A.15.3 Integrating

A Mach-Zehnder acoustic pressure sensor that integrates a pressure-caused phase shift along a several metres long fibre line; a damage-sensing fibre which is severed at some point along its length causing transmission to drop, if a supporting structural member fails, etc.

A.15.4 Distributed

A pressure sensor measuring microbend-induced losses continuously along a length of fibre, combined with an optical time domain reflectometer read-out; a temperature sensor using the ratio of Stokes to anti-Stokes Raman scattered light continuously along a fibre, combined with an optical time domain reflectometer read-out, a strain and/or temperature sensor based on Brillouin scattering, etc. With an appropriate read-out system, signal analysis can also be performed in the frequency domain instead of the time domain.

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