IEC 61757-5-1

Edition 1.0 2021-07

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Fibre optic sensors –
Part 5-1: Tilt measurement – Tilt sensors based on fibre Bragg gratings

Capteurs fibroniques –
Partie 5-1: Mesure d'inclinaison – Capteurs d'inclinaison basés sur des réseaux de Bragg à fibres

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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FIBRE OPTIC SENSORS –

Part 5-1: Tilt measurement – Tilt sensors based on fibre Bragg gratings

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

Draft	Report on voting
86C/1699/CDV	86C/1718/RVC

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

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

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

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INTRODUCTION

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FIBRE OPTIC SENSORS –

Part 5-1: Tilt measurement – Tilt sensors based on fibre Bragg gratings

1 Scope

This part of IEC 61757 defines the terminology, structure, characteristics and their measurement method including the procedures, for an optical tilt sensor based on fibre Bragg gratings (FBGs) as the sensitive element.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts), *International Electrotechnical Vocabulary (IEV)* (available at www.electropedia.org)

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IEC 60068-2 (all parts), *Environmental testing – Part 2X: Tests*

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IEC 61300-2 (all parts), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2X: Tests*

IEC 61754 (all parts), *Fibre optic interconnecting devices and passive components – Fibre optic connector interfaces*

IEC 61757, *Fibre optic sensors – Generic specification*

IEC 61757-1-1:2020, *Fibre optic sensors – Part 1-1: Strain measurement – Strain sensors based on fibre Bragg gratings*

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

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

IEC 62129-3, *Calibration of wavelength/optical frequency measurement instruments – Part 3: Optical frequency meters internally referenced to a frequency comb*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61757, IEC 61757-1-1, IEC 60050 (all parts) and the following apply.

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- IEC Electropedia: available at http://www.electropedia.org/

3.1
tilt
angle of rotation
for a point rotating around a fixed axis, quotient of the length travelled by the point, and the distance from the point to the axis, taken positive or negative, according to whether the rotation is observed to be in the counterclockwise sense or in the clockwise sense, respectively, for an observer looking in the direction opposite to the direction of the axis

Note 1 to entry: Angle of rotation can take any real value, whereas the angle or plane angle defined in geometry (see IEC 60050-102:2007, 102-04-14) is non-negative and restricted to the closed interval [0, π].

Note 2 to entry: The coherent SI unit of angle is radian (symbol rad). Other units accepted for use with the SI are degree (symbol °), minute (symbol ′), and second (symbol ″): 1 ° = (π/180) rad, 1′ = (1/60) °, 1″ = (1/60)′.

[SOURCE: IEC 60050-113:2011, 113-01-43, modified – in the term, "oriented angle" has been replaced with "tilt"]

3.2
FBG tilt sensor
fibre optic sensor that uses one or more fibre Bragg gratings as a sensitive element for tilt measurements in either single axis or multiple axes

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3.3
gauge factor
κ_θ
ratio of the relative change in wavelength $\Delta\lambda/\lambda_0$ to a tilt change $\Delta\theta$ introduced to an FBG tilt sensor and expressed by the gauge factor κ_θ with a unit of 1/rad measured by the manufacturer, and expressed as:

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$$\kappa_\theta = \frac{\Delta\lambda}{\lambda_0\,\Delta\theta}$$

Note 1 to entry: The gauge factor κ_θ is used by manufacturers to express the tilt response of their products.

Note 2 to entry: The gauge factor κ_θ for an FBG tilt sensor assumes a linear characteristic. Considering the whole measurement system (sensor, device, cabling), it can be separately defined for the components of the measurement system. It is only valid for defined conditions. In the case of a non-linear characteristic, the gauge factor κ_θ is considered as linear within a defined permissible error.

3.4
temperature compensation constant
constant for correcting the influence of temperature changes when the tilt is obtained from the wavelength changes

Note 1 to entry: The temperature compensation constant should be provided by the manufacturer.

4 Symbols

For the purposes of this document, the following symbols apply:

C temperature compensation constant

D displacement

$\Delta\theta$ tilt change

ΔT temperature change

κ_θ gauge factor

L length

Λ FBG period

λ_B Bragg wavelength

λ_0 reference wavelength

5 Structure and characteristics

5.1 Fibre Bragg grating (FBG)

Fibre Bragg gratings are phase diffraction gratings inscribed into optical waveguides. They are frequently produced using ultraviolet (UV) light (e.g. by an excimer laser at 248 nm). The fibre is exposed to an interference pattern of this UV radiation. UV photosensitive processes then produce changes in the refractive index of the fibre core which is susceptible to these. The interference pattern is an image in the fibre core of a periodically changing refractive index. Incident and transported light along the fibre is additively superposed for a certain wavelength at these points (constructive interference); this spectral part of the incident light is reflected. In the transmitted light, this wavelength (denoted Bragg wavelength λ_B) is attenuated according to FBG reflectivity.

The value of the reflected Bragg wavelength λ_B is determined from the Bragg condition:

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$$\lambda_B = 2 \cdot n_{eff} \cdot \Lambda \tag{1}$$

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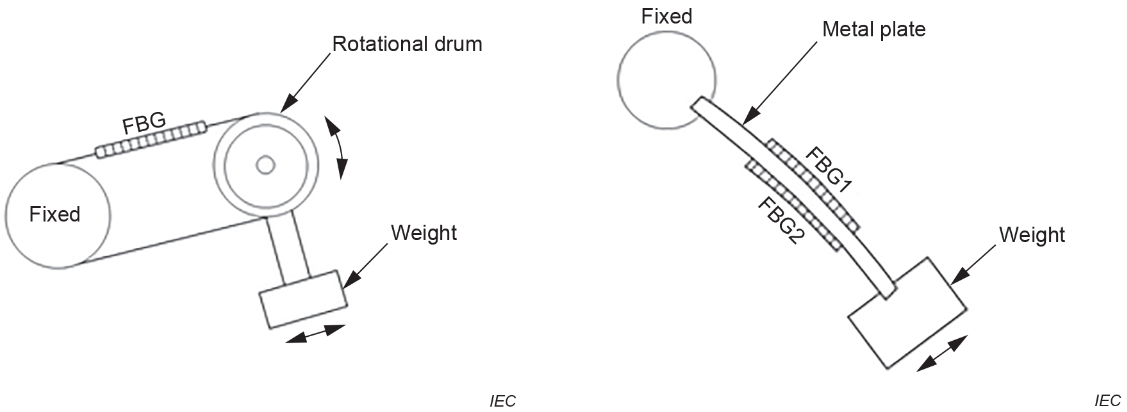
According to Formula (1), the Bragg wavelength λ_B of the FBG depends on the effective refractive index of the FBG and the FBG period Λ. The spectral width of the Bragg wavelength peak is essentially determined by the number of grating periods and the magnitude of the refractive index modulation (see IEC 61757-1-1:2020, 5.1).

5.2 FBG tilt sensor configuration

The FBG tilt sensor can be made of various materials and with various forms as a segment of optical fibre with one or more FBG sensors (in the following denoted Bragg grating fibre). The FBG tilt sensor is capable of measuring both absolute and relative tilt, but it is more suitable for tilt monitoring using relative tilt changes. The reference axis for absolute tilt measurements is the vertical axis.

If the sensor is tilted in such a way that the tilt changes the tensile force applied to the FBG sensor, the tilt can be measured by measuring the reflected Bragg wavelength of the FBG (see Figure 1a) and Figure 1b)). In the example of Figure 1a), the tilt change causes a change in torque due to the repositioning of the weight, which in turn causes a change in the tensile force applied to the FBG, resulting in a change in the FBG reflected wavelength (see Figure 2a), Figure 2b) and Figure 2c)). The method used to convert a tilt change into a change of the Bragg wavelength is not part of this document and can be different depending on the manufacturer.



a) rotation type **b) metal plate type**

Figure 1 – Examples for measuring single axis tilt changes

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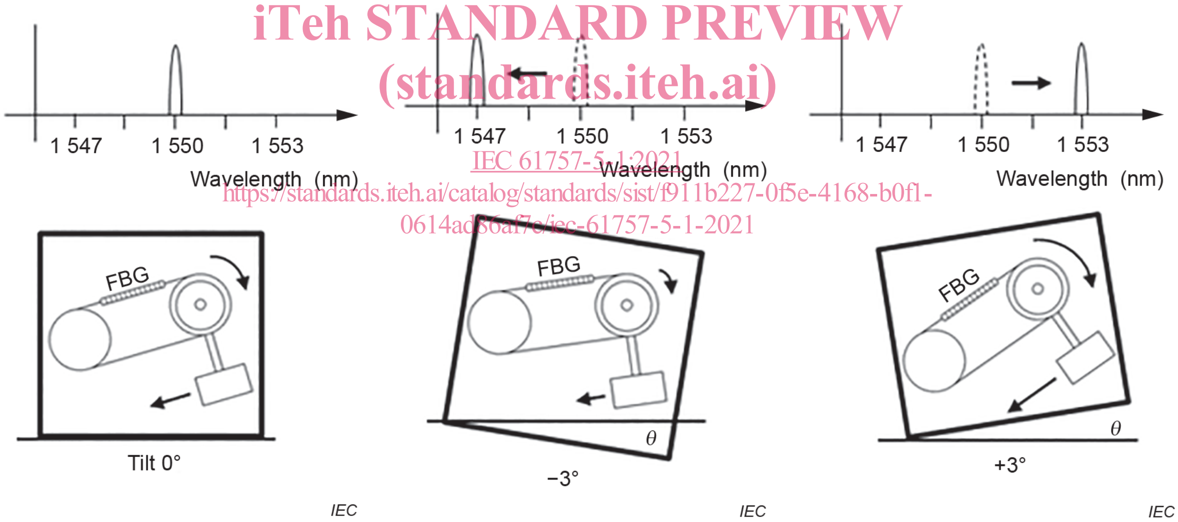

a) no tilt **b) clockwise tilt** **c) counterclockwise tilt**

Figure 2 – Examples of Bragg wavelength change caused by tilt

A broadband source and a spectrometer are connected to the tilt sensing FBG by a circulator as shown in Figure 3. An additional FBG (FBG1), placed in close proximity to the tilt sensing FBG (FBG2), is used for temperature compensation, while FBG2 performs tilt measurements. FBG1 and FBG2 can be connected in parallel or in series, as shown in Figure 3.

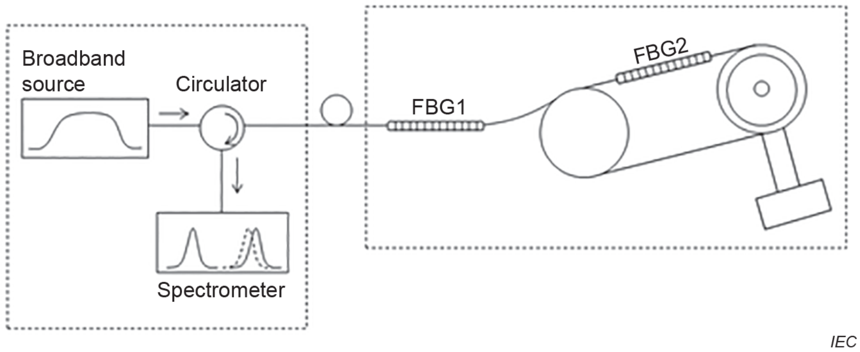

Figure 3 – Example of tilt sensor using FBG (schematic diagram)

5.3 Reference wavelength

Different evaluation methods and different devices result in different Bragg wavelengths being measured for the same filter function of the FBG. In the context of this document, therefore, the result of the wavelength measurement after installation of the FBG tilt sensor with the specified device will be denoted as the reference wavelength λ_0.

The reference wavelength is not necessarily the same as the Bragg wavelength specified by the manufacturer of the FBG. If the FBG is prestrained, for example, there is a difference between the reference wavelength and the Bragg wavelength. If the FBG is not prestrained, the difference between the reference wavelength and the Bragg wavelength is usually very small, so that both wavelength values can be used without significant error.

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If the reference wavelength is measured when the measurement cycle is started, this wavelength measurement can be considered as the zero point measurement value.

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5.4 Stability behaviour

5.4.1 Drift and creep

Stability, in general, is the ability of a measurement system to maintain its metrological characteristics and meet other specifications over the intended time of operation. Stability, in the context of this document, describes the property of the applied FBG tilt sensor to keep its optical characteristics constant over a period of use determined by the objectives, or to show only a small permissible deviation.

Variations in the measured value might occur:

– when the materials concerned are subject to long-term stress (creep);
– without loading stress (zero point drift).

This can be caused by the slow progress of chemical or physical degradation within the materials used (e.g. ageing), or by a change in the initial physical conditions (e.g. temperature or humidity).

Creep is a quantity that depends on the materials employed, the set-up of the sensor, and the type of operation, and can only be determined experimentally. According to current experience, the error contribution resulting from creep remains irrelevant within the scope of the given uncertainty of measurement for the gauge factor κ_θ, when the bonding material prescribed by the manufacturer is used.

Drift is a slow change of the metrological characteristics of the measurement system. The drift error of an FBG sensor is negligibly small, according to the state of the art; hence for this document, no further specification is required. However, if drifts are generated by a modified production process, for example, or by applying inadequate recoating material, the drift should be stated.