IEC 61757-6-1

Edition 1.0 2024-01

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Fibre optic sensors –
Part 6-1: Displacement measurement – Displacement sensors based on fibre Bragg gratings

Capteurs fibroniques –
Partie 6-1: Mesure de déplacement – Capteurs de déplacement basés sur des réseaux de Bragg sur fibre

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FIBRE OPTIC SENSORS –

Part 6-1: Displacement measurement – Displacement sensors based on fibre Bragg gratings

FOREWORD

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IEC 61757-6-1 has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics. It is an International Standard.

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

Draft	Report on voting
86C/1874/CDV	86C/1891/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/publications.

A list of all parts in the IEC 61757 series, published under the general title *Fibre optic sensors*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

INTRODUCTION

This document is part of the IEC 61757 series, which is dedicated to fibre optic sensors. Generic specifications for fibre optic sensors are defined in IEC 61757.

The individual parts of the IEC 61757 series are numbered as IEC 61757-M-T, where M denotes the measure and T the technology. The IEC 61757-6-T series is concerned with displacement measurements.

FIBRE OPTIC SENSORS –

Part 6-1: Displacement measurement – Displacement sensors based on fibre Bragg gratings

1 Scope

This part of IEC 61757 defines the terminology, structure, and measurement methods of optical displacement sensors based on fibre Bragg gratings (FBGs) as the sensing element. This document also specifies the most important features and characteristics of these fibre optic displacement sensors and defines procedures for measuring these features and characteristics.

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

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

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61757, IEC 61757-1-1 and the following apply.

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

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

3.1.1
displacement
D
distance change between two given points

Note 1 to entry: A displacement is designated as an absolute displacement if only one of the two given points changes its position.

Note 2 to entry: A displacement is designated as a relative displacement if both of the two given points change their position.

3.1.2
FBG displacement sensor
fibre optic sensor that uses one or more fibre Bragg gratings as a sensing element for displacement measurements

3.1.3
displacement conversion factor
κ_{D}
ratio of the relative change in wavelength $\Delta\lambda / \lambda_0$ to a displacement change ΔD introduced to an FBG displacement sensor

Note 1 to entry: The displacement conversion factor κ_{D} is calculated as

$$\kappa_{\mathrm{D}} = \frac{\left(\dfrac{\Delta\lambda}{\lambda_0}\right)}{\Delta D}$$

Note 2 to entry: The displacement conversion factor κ_{D} is used by manufacturers to characterize the displacement response of their products.

Note 3 to entry: The conversion factor κ_{D} for an FBG displacement sensor assumes a linear relation between wavelength change and displacement. Considering the whole measurement system (sensor, device, and 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 relation between wavelength change and displacement is considered to be linear within a defined permissible measurement error.

Note 4 to entry: The term displacement sensitivity, expressed for example in pm/mm, is used by some manufacturers to characterize the displacement response of their products.

3.1.4
temperature compensation constant
C
constant for correcting the influence of temperature changes when the displacement is obtained from wavelength changes

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

Note 2 to entry: The term temperature sensitivity, expressed for example in (pm/°C), is used by some manufacturers to characterize the influence of temperature changes of their products.

3.2 Symbols

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

R_{FBG}	reflectivity of the FBG
n_{eff}	effective refractive index of the FBG
ΔD	displacement change
ΔT	temperature change
Λ	FBG period
λ_B	Bragg wavelength
λ_0	reference wavelength

3.3 Abbreviated terms

FBG	fibre Bragg grating
FWHM	full width at half maximum
SNR	signal-to-noise ratio
UV	ultraviolet

4 Structure and characteristics

4.1 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. from 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 this UV light. The interference pattern is imaged onto the fibre core to permanently change the refractive index of the fibre core, so that the refractive index varies periodically along the fibre. Incident and transported light is reflected by these periodic refractive index changes along the fibre. At a certain wavelength, the reflected light is additively superimposed (constructive interference); this spectral part of the incident light is reflected back to the input port of the fibre. In the transmitted light, this wavelength (denoted Bragg wavelength λ_B) is attenuated accordingly, due to the FBG reflectivity.

The value of the reflected Bragg wavelength λ_B is determined by the Bragg condition shown in Formula (1).

$$\lambda_B = 2 n_{eff} \Lambda \quad (1)$$

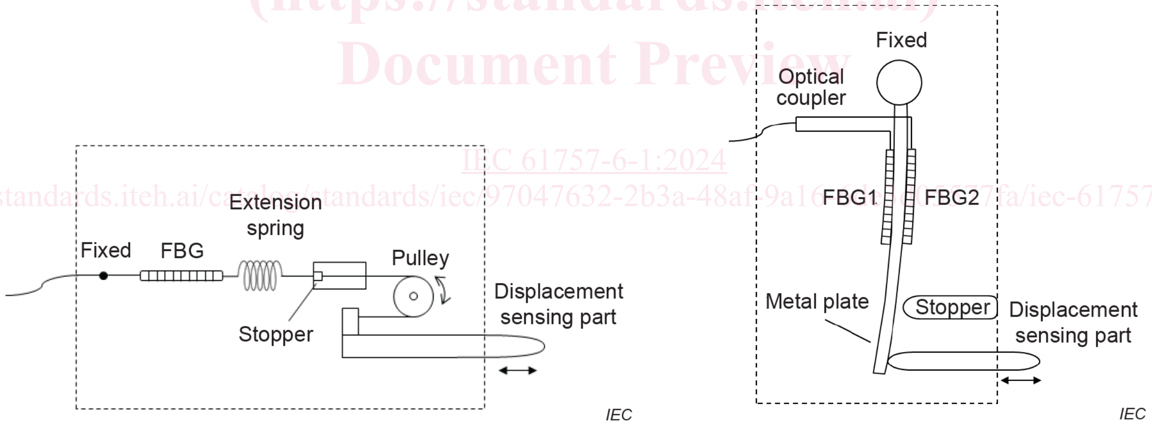
According to Formula (1), the Bragg wavelength λ_B of the FBG depends on the effective refractive index n_{eff} of the FBG and on the FBG period Λ. The spectral width of the Bragg wavelength peak is determined by the number of grating periods and the magnitude of the refractive index modulation (see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

4.2 FBG displacement sensor configuration

The FBG displacement sensor can be fabricated from various materials and in various forms (using one or more FBGs as sensing elements). The FBG displacement sensor is typically used to monitor the displacement occurring between two points of different objects, or between two parts of the same object. One example is monitoring of displacement changes at expansion joints that are installed in bridges to prevent damage to the structure; these joints contract and expand due to temperature changes. Another example of detecting displacement changes is monitoring of crack size changes in structures where cracks have occurred.

The method used to convert a displacement change into a change of the Bragg wavelength of an FBG depends on the manufacturer of the displacement sensor. There are a variety of methods, but a comprehensive description of these methods is outside the scope of this document.

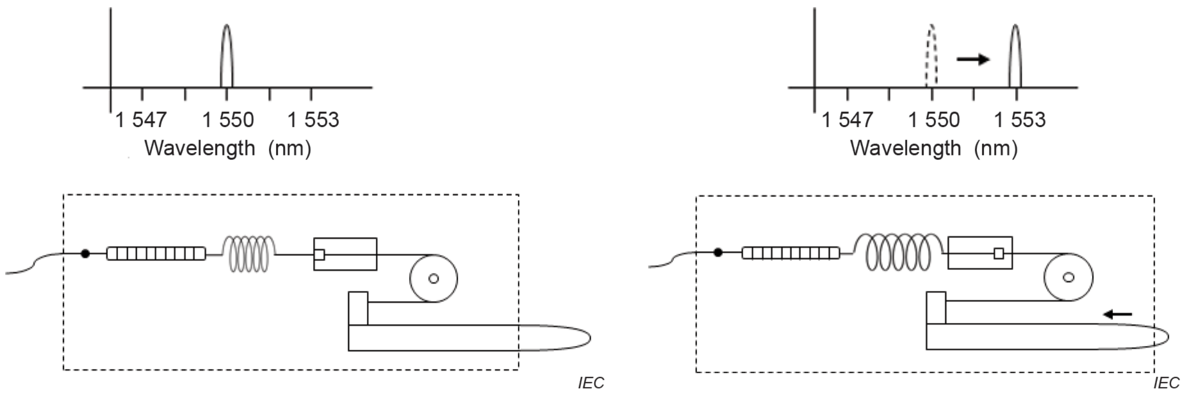
As an example, the FBG displacement sensor can be configured so that the movement of a stylus (which is the displacement sensing part) by means of a mechanical transducer causes a corresponding strain change in the FBG, as shown in Figure 1 for a spring-type sensor and for a metal-plate-type sensor. This strain change in the FBG then changes the reflected Bragg wavelength of the FBG, as shown in Figure 2 and Figure 3. Hence, the displacement can be determined by measuring the reflected Bragg wavelength of the FBG.



a) Spring type **b) Metal plate type**

Figure 1 – Examples of sensor types for measuring displacement changes

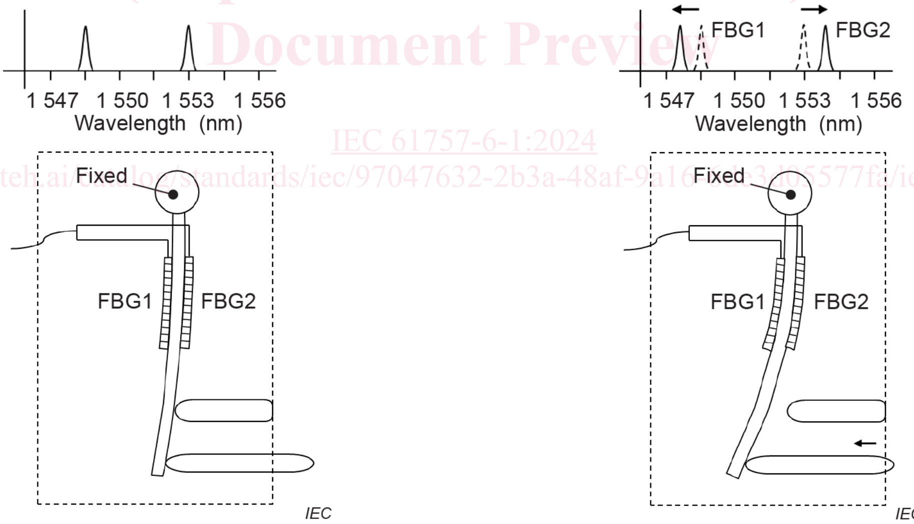
In the spring-type sensor shown in Figure 1 a), a displacement change causes a pulley to rotate, which changes the length of a tensile spring that is attached to an FBG. The resulting change in the tensile force applied to the FBG causes a strain change in the FBG, which in turn changes the reflective wavelength of the FBG, as illustrated in Figure 2 a) and Figure 2 b). When installing the FBG displacement sensor shown in Figure 2 a), the stopper is often placed near the centre of the expected displacement changes, so that positive as well as negative displacement changes can be detected. If displacement changes are expected to occur in only one direction, a larger change in displacement can be measured by placing the stopper more towards the left or right side.



a) No displacement change **b) With wavelength and displacement change**

Figure 2 – Bragg wavelength change caused by displacement in a spring-type sensor

In the metal-plate-type sensor shown in Figure 1 b), a change in displacement causes an elastic metal plate to bend. The change in the shape of the metal plate is detected by two FBGs, denoted FBG1 and FBG2, which are attached to both sides of the metal plate, as shown in Figure 3 a). When the displacement-measuring stylus moves from its original position to the left direction, the elastic metal plate bends further to the left, which causes a contraction of FBG1 and an expansion of FBG2. Since the contraction of FBG1 results in increased stress and the expansion of FBG2 in increased strain, the displacement changes the reflective Bragg wavelengths of the two FBGs in opposite directions, as shown in Figure 3 b).



a) No displacement change **b) With wavelength and displacement change**

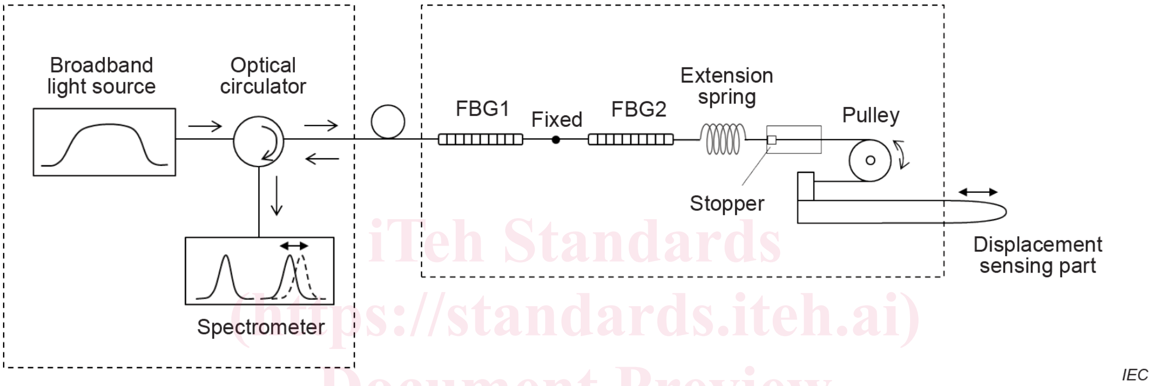
Figure 3 – Bragg wavelength changes caused by displacement in a metal-plate-type sensor

A broadband light source and an optical spectrometer can be used to measure the change in the Bragg wavelength of an FBG. The light source and the spectrometer are typically connected to the displacement sensing FBG via an optical circulator, as shown schematically in Figure 4 for the spring-type and the metal-plate-type sensors.

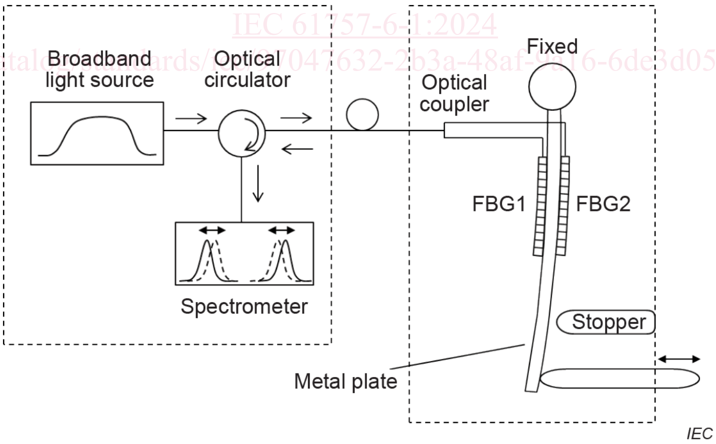
In the spring-type sensor shown in Figure 4 a), an additional FBG (denoted FBG1) is inserted near the displacement sensing FBG (denoted FBG2) to allow for compensation of the temperature dependence of FBG2 (as described in 5.5.3). The additional FBG1 measures only temperature changes, whereas FBG2 measures displacement and temperature changes. FBG1 and FBG2 can be connected in series, as shown in Figure 4 a), or in parallel, like in the arrangement shown in Figure 4 b).

The metal-plate-type sensor shown in Figure 4 b) employs two FBGs for the displacement measurement. An additional FBG for temperature measurement is not necessary in this arrangement, because the displacement change is calculated from the differential change in the reflected wavelengths of FBG1 and FBG2. If the Bragg wavelength variations due to temperature changes are identical in both FBGs, the temperature dependence of the Bragg wavelength is automatically compensated.

The metal-plate-type sensor of Figure 4 b) uses an optical coupler with 3 dB splitting ratio to connect FBG1 and FBG2 to the broadband light source and spectrometer.



a) Spring type with additional FBG for temperature measurement



b) Metal plate type using two FBGs for displacement measurement

Figure 4 – Schematic diagrams of displacement sensors using two FBGs

4.3 Reference wavelength

The Bragg wavelength measured with a given FBG can depend on the evaluation method used and, more importantly, on the specific installation of the FBG. In the context of this document, the wavelength measured after installation of the FBG in the displacement sensor is denoted as the reference wavelength λ_0