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



IEC 61757-6-1:2024-01(en-fr)



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

ICS 33.180.99

ISBN 978-2-8322-8134-5

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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# FIBRE OPTIC SENSORS –

# Part 6-1: Displacement measurement – Displacement 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/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- withdrawn, or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**
$\kappa_D$
ratio of the relative change in wavelength $\Delta\lambda$ / $\lambda_0$ to a displacement change $\Delta D$ introduced to an FBG displacement sensor

Note 1 to entry: The displacement conversion factor $\kappa_D$ is calculated as

$$\kappa_D = \frac{\left(\frac{\Delta\lambda}{\lambda_0}\right)}{\Delta D}$$

Note 2 to entry: The displacement conversion factor $\kappa_D$ is used by manufacturers to characterize the displacement response of their products.

Note 3 to entry: The conversion factor $\kappa_D$ 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

$\Delta D$ displacement change

$\Delta T$ temperature change

$\Lambda$ FBG period

$\lambda_B$ Bragg wavelength

$\lambda_0$ 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 $\lambda_B$) is attenuated accordingly, due to the FBG reflectivity.

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

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

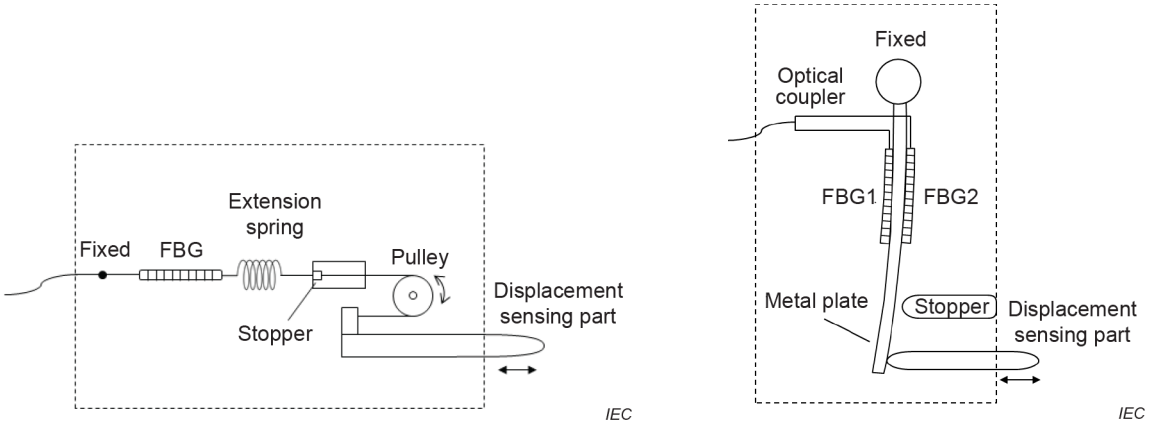
According to Formula (1), the Bragg wavelength $\lambda_B$ of the FBG depends on the effective refractive index $n_{eff}$ of the FBG and on the FBG period $\Lambda$. The spectral width of the Bragg wavelength peak is determined by the number of grating periods and the magnitude of the refractive index 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.