TECH NOTE :: Temperature compensation of FBG based sensors

Version: 2022-04-07
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Status: public

Fiber Bragg Grating working principle

The Fiber Bragg Grating (FBG) is a periodic microstructure that is written inside the core of an optical fiber. When insident light from a broadband source hits the FBG, a very narrow width spectrum, centered at the Bragg wavelength (λ_0), is reflected and the remaining light continues its way through the optical fiber.

The variation of the refelcted wavelength ($\Delta\lambda$) of an FBG is dependant on strain and temperarure, which makes this microstructure totally suited to be used as a sensor. This dependency is expressed in Equation 1.

$$\frac{\Delta\lambda}{\lambda_0} = k\Delta\varepsilon + (\alpha + \zeta)\Delta T$$

Equation 1

Where:

- k is the gauge factor of the Bragg grating, dimensionless value that correlates strain with the wavelength variation towards the Bragg wavelength of an FBG.
- α is the thermal expansion of silica and ζ the thermo-optic coefficient of the fiber

FBGs are commonly used as strain sensors by direct application to a material that will suffer deformation. They can also be used as temperature sensors provided that strain is isolated from the fiber Bragg grating area. Because of its characteristics, FBGs can be used in he creation of transducers where the measurement is transfered to a deforming FBG.

The fiber Bragg grating measuring principle is based on light traveling through silica fiber the technology becomes suited for many harsh applications for conventional sensing:

- Long distances
- EMI/RFI areas
- Explosive areas
- High voltage
- Large sensor count
- Multifuncional measurements with the same acquision equipment

Check out our website for further information on the technology and offered solutions.

Temperature compensation of Fiber Bragg Grating sensors

When performing measurements with FBG based sensors care must be taken on the effects that temperature changes impose on that measurement.

Temperature compensation of strain sensors

Temperature influence on the strain of the specimen

The measured strain on a mechanically loaded specimen that is also subjected to a temperature change is affected by the load (ε_{load}) and the thermal expansion of the specimen material (ε_{CTE})

$$\varepsilon_{Real} = \varepsilon_{Load} + \varepsilon_{CTE}$$

Equation 2

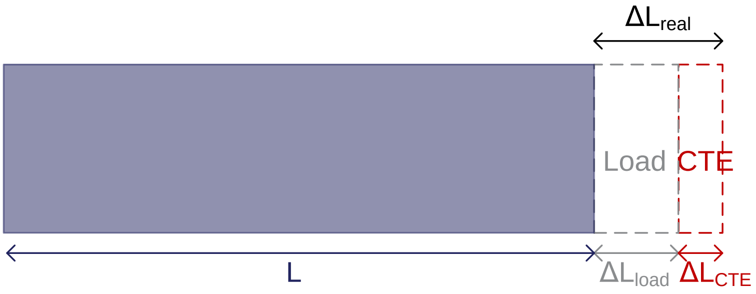

Figure 1 Elongation of a material when subjected to load and temperature changes

Temperature influence on the FBG measurement

The thermally induced wavelength variation on an FBG that is attached to a certain material can be taken from Equation 1 considering that there is no strain, and that the thermal expansion of the silica is also constrained because the sensor is attached to the material and silica will not expand.

$$\frac{\Delta\lambda}{\lambda_0} = \zeta.\Delta T$$

Equation 3

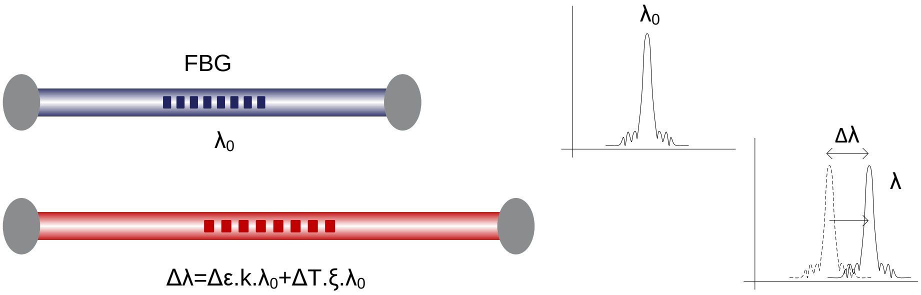

Figure 2 Strain and temperature effect of an attached FBG

Temperature compensation of strain sensors using Temperature measurements

Temperature compensation of both thermal effects

When considering encapsulated sensors, the temperature effect on the measurement is experimentally determined and provided on the sensor documentation, as it might differ from the theoretical silica behavior. This influence is expressed by the Temperature Cross Sensitivity (TCS) as below:

$$\frac{\Delta\lambda}{\lambda_0}.\frac{1}{k}.10^6 = \varepsilon + CTE.\Delta T + TCS.\Delta T$$

Equation 4

where

- CTE is the coefficient of thermal expansion of the material onto which the strain sensor is installed (also known as α of the material). CTE is expressed in (µm/m)/°C.
- k is the dimension-less strain sensitivity of the sensor (also known as gauge factor or k factor). It is indicated on the characteristic sheet.
- ε is the pure mechanical strain, in µm/m, distinguished from the temperature-induced strain signal.
- TCS is the thermal cross sensitivity of the strain sensor, indicated on the characteristic sheet. The TCS is expressed in (µm/m)/°C.

To obtain the temperature-compensated strain signal ε, the latter two summands need to be subtracted.

$$\varepsilon = \frac{\Delta\lambda}{\lambda_0}.\frac{1}{k}.10^6 - TCS.\Delta T - CTE.\Delta T$$

Equation 5

Temperature variations can be attained by using an additional temperature sensor next to the strain sensor, ensuring that the temperature of both sensors is the same. Temperature measurements can be performed with FBG based temperature sensors, or sensors based on other technologies.

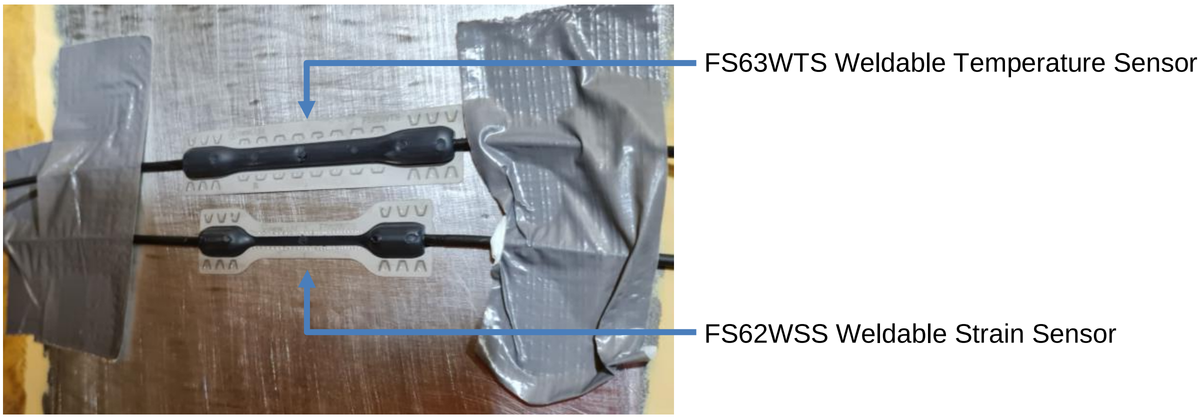

Figure 3 Installed weldable strain and temperature sensors

Care must be taken on the reference instant that should correspond simoultaniously to the „zero strain“ moment and the reference temperature.

$$\varepsilon = \frac{\Delta\lambda}{\lambda_0}.\frac{1}{k}.10^6 - (TCS + CTE).(T - T_0)$$

Equation 6

Where λ_0 is the reference wavelength at the zero moment of the strain sensor, in nm, and T_0 is the temperature, in ºC, measured at the same instant.

Temperature compensation of strain sensors using an optical compensation element

Instead of having an absolute temperature measurement, it is also possible to use an FBG sensor as a compensation element.

This can be an FBG based:

1. temperature sensor (without calibration) from HBK FiberSensing;
2. strain sensor applied to the same material of the specimen-under-test that is isolated from mechanical strain and subjected to the same temperature changes (dummy strain);
3. strain sensor applied to a different material, with a known CTE, that is isolated from mechanical strain and subjected to the same temperature changes;
4. terminal fiber, free from strain and subjected to the same temperature changes.

The temperature variation of a compensation element is given by Equation 4 where mechanical strain is zero:

$$\frac{\Delta\lambda_{TC}}{\lambda_{0\,TC}}.\frac{1}{k_{TC}}.10^6 = \varepsilon + CTE_{TC}.\Delta T + TCS_{TC}.\Delta T$$

$$(T - T_0) = \frac{\Delta\lambda_{TC}}{\lambda_{0\,TC}}.\frac{1}{k_{TC}}.10^6.\frac{1}{TCS_{TC} + CTE_{TC}}$$

Equation 7

Which leads us to the corrected strain using a compensation element:

$$\varepsilon = \frac{\Delta\lambda}{\lambda_0}.\frac{1}{k}.10^6 - (TCS + CTE).\frac{\Delta\lambda_{TC}}{\lambda_{0\,TC}}.\frac{1}{k_{TC}}.10^6.\frac{1}{TCS_{TC} + CTE_{TC}}$$

Equation 8

$$\varepsilon = \frac{\Delta\lambda}{\lambda_0}.\frac{1}{k}.10^6 - \frac{\Delta\lambda_{TC}}{\lambda_{0_{TC}}}.\frac{1}{k_{TC}}.10^6.\frac{TCS + CTE}{TCS_{TC} + CTE_{TC}}$$

For the cases mentioned above, the equation becomes:

Non calibrated HBK FiberSensing temperature sensor	
$\varepsilon = \left(\frac{\Delta\lambda}{\lambda_0}.\frac{1}{k} - \frac{\Delta\lambda_{TC}}{\lambda_{0_{TC}}}.\frac{TCS + CTE}{TCF_{TC}}\right).10^6$	Where TCF is the temperature compensation factor given on the sensor characteristic sheet
Strain sensor applied to the same type of material (dummy strain)	
$\varepsilon = \left(\frac{\Delta\lambda}{\lambda_0} - \frac{\Delta\lambda_{TC}}{\lambda_{0_{TC}}}\right).\frac{1}{k}.10^6$	Simplified because sensor type is the same (same TCS and same k factor) and material is the same (same CTE)
A strain sensor applied to a different material	
$\varepsilon = \left(\frac{\Delta\lambda}{\lambda_0}.\frac{1}{k} - \frac{\Delta\lambda_{TC}}{\lambda_{0_{TC}}}.\frac{1}{k_{TC}}.\left(\frac{TCS + CTE}{TCS_{TC} + CTE_{TC}}\right)\right).10^6$	A terminal FBG can be considered as a strain FBG sensor applied to silica

HBK catman software supports you on getting temperature corrected mechanical strain by embedding some of the calculation algorithms. The used option can be easily selected and only the correct coefficients need to be inserted. For the configurations not supported by catman, it is possible to create a computational channel with a user defined formula. The table below summarizes how to proceed with temperature compensation for the cases described:

Sensor adaptation	Computational channel
Temperature measurements	Non calibrated HBK FiberSensing temperature sensor
Strain sensor applied to the same type of material (dummy strain)	A strain sensor applied to a different material

Note:

More information on how to proceed in catman to configure temperature compensation of optical strain sensors please see the software documentation or the dedicated technote on the topic.