Strain and Temperature Measurement with Optical Fiber Bragg Grating Sensor

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What is a fiber Bragg grating?

Optical fiber Bragg grating:

- Quasi-sinusoidal refractive index variation:
  \[ n(z) = n_0 + \Delta n \sin \left( \frac{2\pi z}{\Lambda} + \theta(z) \right) \]
- Acts as a filter:
  \[ \lambda_{\text{center}} = 2n\Lambda \]

n and Λ depend on temperature, strain, pressure => can be used as a sensor

Advantages

- linear measurement, relative signal (no calibration)
- high temperature and strain sensitivity
- multiplexing capabilities
- long term stability
- immune to electromagnetic interference
- flexibility and small diameter => embedding in structure possible
- independent of the intensity of the light (spectral measurement)

Grating inscription

Photosensitivity of silica: a UV pattern is printed into the fiber core as index variation

- holographic method: the fiber is positioned under classical interferometric fringes
- phase mask method: the fiber is positioned under the interferometric fringes obtained by the one order diffraction produced by the mask

Principle of the sensors

- Periodical structure of pitch Λ formed by refractive index (n) variation of the core
- Characteristic wavelength of the grating: \( \lambda_g = 2n\Lambda \)
- Variation of the Bragg wavelength (hypothesis: isotropic optical fiber under uniaxial longitudinal strain \( \varepsilon \))
  \[ \frac{\Delta \lambda}{\lambda} = a\varepsilon + b\Delta \rho + c\Delta T \]
- In detail, thermal variation:
  \[ \frac{\Delta \lambda}{\lambda} = (a + \frac{\varepsilon}{2})\Delta T \]
- In detail, longitudinal strain:
  \[ \frac{\Delta \lambda}{\lambda} = \left[ 1 - \frac{\varepsilon}{2} \right] \rho \leq (1 - \rho) \varepsilon = b\varepsilon \]

Applications: structural health monitoring of civil construction, intelligent sensing for innovative structures, composite (aeronautic) structure, seismology, medical and chemistry, measures and controls during industrial process, ...

Experimental measurement device

Peak extraction: minimization (Levenberg-Marquardt) of \( f(\lambda) = I_0 + \lambda \frac{\Delta \lambda}{\lambda} \)

Metrological performances

- \(-100 < T < 500 \degree C\)
- \(0.1 \leq P < 100 \text{ MPa}\)
- \(10^{-4} \% < \varepsilon < 2 \%\)
- Thermal: 12 pm / °C
- Strain: 1.2 pm / °C
- Hydrostatic pres.: -4.5 pm / MPa

Experimental validation

Bare FBG submitted to tension

FBG stuck on the surface of a specimen - comparison with strains measured by mechanical extensometer and full field strain measure (stereocorrelation)

FBG embedded with epoxy resin in a groove - comparison with strains measured by mechanical extensometer and strain gauge

Temperature variation of the Bragg wavelength for stuck and embedded FBGs: sensitivity depends on the material