Distributed Strain or Temperature Sensing using chirped fiber Bragg gratings

The Challenge

The use of fibre optic sensing to monitor distributed strain or temperature profiles has become widespread. The advantages of miniature size, light weight, long reach, EMI immunity and intrinsic safety have led to fiber optic sensing being adopted in numerous industries including oil & gas, energy generation, chemical, civil engineering and aerospace. There are two principal methods of distributed strain or temperature sensing; (i) monitoring the Brillouin or Raman light backscattered from an optical fiber (DSS/DTS), or (ii) measuring the wavelengths reflected from an array of multiple fibre Bragg gratings (FBGs). However, each method has its limitations.

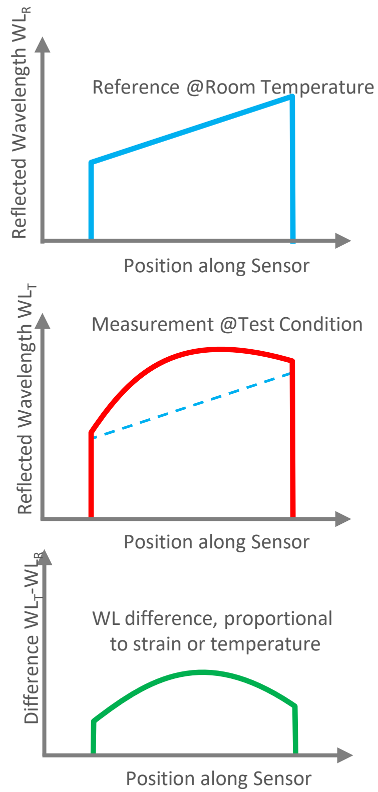
Whilst DSS and DTS benefit from being truly distributed they require very long integration times to achieve useable accuracy and so cannot measure dynamic changes. Furthermore, the spatial resolution of their measurements is limited to the order of 1m.

FBG Array sensing does offer dynamic, accurate measurements and high spatial resolution, but does not offer the extremely high multiplexing capability of DSS and DTS.

There are some applications where all three benefits are required together, which presents a challenge for fiber optic sensing.

The Solution

A FBG works by reflecting a nominal wavelength of light which varies with strain or temperature on the fiber at the FBG location. A chirped fiber Bragg grating (CFBG) is a type of custom FBG designed such that the nominal reflected wavelength changes along its length. This allows the CFBG to reflect a wide range of wavelengths at different locations. Considering the figures below, once can see how the spectrum reflected from the CFBG under a test temperature condition (centre) can be subtracted from a reference spectrum taken at toom temperature (left) to extract the distributed temperature profile along the CFBG in the test condition. The exact same principal applies to the measurement of distributed strain.



Showing how a long chirped FBG can be used to measure distributed strain or temperature

Proximion

Proximion AB
Skalholtsgatan 10, SE-164 40 Kista
Sweden

Phone: +46 8 750 48 88
info@proximion.com
www.proximion.com

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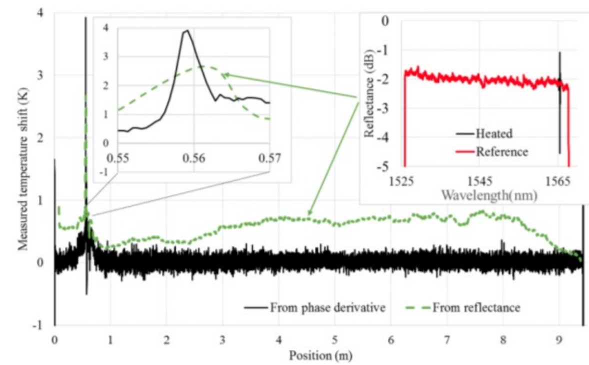
With this unique capability of a CFBG in mind, researchers at Proximion set out to demonstrate how their chirped gratings can provide distributed strain and/or temperature measurement along its length, by interrogating the reflection either in the time domain (phase derivative) or the wavelength domain. The results, presented to the [25th Optical Fiber Sensors Conference], are summarised below.



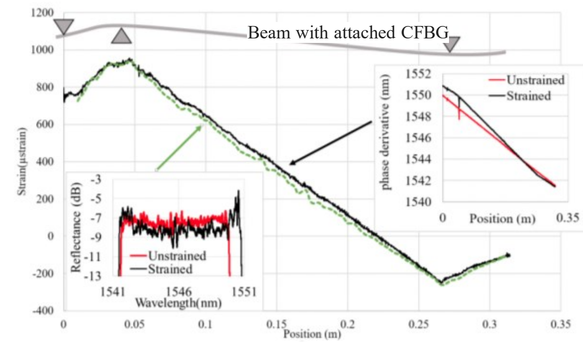
Temperate testing results summary

Temperature Testing

After applying a localized temperature to a part of the CFBG, the localized heating appears in the time-domain phase derivative as a narrow peak with a width of 4 mm and the noise level across the entire length of the grating is approximately 0.1 K (or 0.9 µstrain if measuring strain). The temperature was also determined by a frequency-domain analysis of the spectral reflectance, which resulted in a 1 K offset and a peak width of 10 mm. Despite this difference, the calculated temperature remains highly useful.

Strain Testing

To evaluate the system performance for strain sensing, a second CFBG sample was mounted on a beam and subjected to bending, creating a zig-zag shape. The distributed strain profile was determined using both the time-domain method and the frequency-domain method. The results from both methods are consistent and capable of detecting discontinuities in the strain derivative. This proves that CFBGs can be beneficial in monitoring both localized distortions caused by joints or cracks and overall strain profiles.



Strain testing results summary

In this study, Proximion has demonstrated that our long, chirped fiber Bragg gratings (CFBGs) have the ability to fill the unmet need in fiberoptic temperature and strain sensing. The strain gradient monitoring of CFBGs can be used for many structural health monitoring applications, such as aircraft wing or structural beam deflection, or integrity monitoring of bonded or welded joints. The temperature gradient monitoring capability can be used, for instance, to monitor the temperature profiles in a fluid column to detect fluid interfaces or stratification.