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MULTIPLEXING METHODS FOR FIBRE OPTIC STRAIN SENSORS

[†]J P Dakin, M G Xu and H Geiger

Abstract

The paper briefly reviews a number of methods for multiplexing optical-fibre-based strain sensors. These are intended for application for structural monitoring, for example in aerospace composites or civil engineering structures. Particular emphasis is placed on methods for addressing arrays of sensors using acousto-optic tunable filters and optical time domain reflectometry which have been recently developed in the authors' laboratory.

1.0 Introduction

Optical fibre sensors have many advantages for monitoring strain in mechanical structures. The primary features are listed below:-

(i) Silica is an excellent elastic material, largely free from creep and fatigue problems.
(ii) The sensors have total immunity to electromagnetic interference and lightning strike, etc.
(iii) They have excellent corrosion resistance, as silica is resistant to most chemicals.
(iv) Being non-metallic, the sensor cannot promote electrolytic corrosion.
(v) A thin fibre sensor has a smaller influence on mechanical structures.
(vi) A fibre sensor can be produced as a uniform cylinder, for both sensing and telemetry, avoiding stress concentration points and fragile connections.

2.0 Existing methods for addressing Bragg grating sensors

Fibre optic Bragg grating sensors are attracting considerable interest for a number of sensing applications[1-9] because of their wavelength-encoded operation and intrinsic nature. In order to interrogate and demultiplex a number of in-fibre Bragg grating sensors, whether or not they are in a common fibre path, it is necessary that the instantaneous central wavelength of each individual sensor can be identified.

Various schemes to detect small peak wavelength shifts of the gratings have been developed.[5-9] These include the edge-filter demodulation method[5] where a sharp edge of a filter is used to convert wavelength changes to amplitude variations, interferometric-based approaches,[6-7] the use of frequency-locked grating pairs[8] and laser-sensor concepts where the sensor is an active lasing device that determines the frequency.[4,9]

2.1 Our frequency-agile addressing system using an acousto-optical tunable filter

All the above methods have limitations when it is desired to interrogate the wavelength of a large number of fibre-gratings in a frequency-agile manner. In this paper we present a new method of constructing a interrogating system for in-fibre Bragg grating sensors using an acousto-optic tunable

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[†] Optoelectronics Research Centre, University of Southampton, Highfield, Southampton SO9 5NH, UK

filter (AOTF). This type of filter possesses the desired frequency-agile capability for random access and has a wide tuning range.[10] At constant temperature, its peak transmission wavelength is determined solely by the frequency of an RF drive signal and it is therefore suitable for both dynamic and quasi-static strain sensing and for multiplexed sensing systems. In addition, the same detection system can be used to measure the Bragg wavelengths of the gratings in either reflective or transmissive configuration.

Our experimental system is shown schematically in Fig.1. Light from a broadband optical source (ELED) is coupled, via the in-fibre grating to be measured, through the AOTF and then to a detector. The operating principle of the transmission type of AOTF is described in detail elsewhere.[10] As already mentioned, the wavelength of the light transmitted by the AOTF is a function of the RF frequency. In order to track the instantaneous Bragg wavelength, it is feasible to employ a feedback signal to lock the mean optical wavelength of the filter to the instantaneous Bragg wavelength of the in-fibre grating. This involves dithering the applied RF frequency about a nominal value (ie. FSK) and detecting the amplitude modulation of the received optical carrier. Assuming that the AOTF mean wavelength is proportional to applied RF frequency over the measurand-induced wavelength shift of each in-fibre grating, then for symmetrical grating and filter responses, the amplitude modulation at the dither frequency is zero when the mean wavelength of the AOTF coincides with the Bragg wavelength of the grating. This condition can be achieved by adjusting the mean frequency of the FSK signal.

The FSK signal is conveniently generated using a voltage controlled oscillator (VCO), with a low-frequency square wave input plus a DC bias signal to tune the mean frequency. The electronics system shown in Fig.1 should serve to lock the mean frequency of the AOTF to the condition where the amplitude modulation is zero. The mean frequency of the VCO would then provide an indication of the corresponding instantaneous Bragg wavelength of the sensor. For multiplexing, it would, of course, be necessary to apply an impulse to the VCO input to cause it to address and then lock onto a different in-fibre grating. Alternatively the filter could be simultaneously driven by multiple RF signals of different frequencies, each set to track a particular grating as described above.

2.2 Experiments and discussion

In our experimental demonstration, we have shown the basic concept to be feasible by operating the system in open loop configuration. The broadband source used was a 1300 nm single-mode fibre-pigtailed ELED, which launched ~50 μW of output power over a ~56 nm bandwidth (FWHM). The sensing grating, having a nominal (ie. unstrained and at room temperature) Bragg wavelength of ~1298 nm, a peak reflectivity of 99% and a bandwidth of ~1 nm (FWHM), was incorporated between the optical source and the AOTF. The AOTF (Crystal Technology, MID-IR AOTF) had a wavelength tuning range of 1.2 μm - 2.5 μm and a resolution (FWHM) of 4 nm. We used a commercial RF signal generator (MARCONI 2031) as a VCO. The frequency deviation of the FSK-modulated drive signal to the AOTF was chosen to be 360 KHz to obtain optimum sensitivity for the particular AOTF/grating configuration. The mean RF drive frequency was manually chosen to be 111.58 MHz to set the mean AOTF wavelength to the nominal Bragg wavelength.

Fig.2 shows the system output from the optical detector, with the modulation-input frequency to the VCO set to 200 Hz, and with the mean RF frequency detuned from the matching condition. The modulation signal at the detector becomes zero only when the mean AOTF wavelength matches the instantaneous Bragg-grating wavelength. For the purpose of our initial feasibility experiment, the temperature measurement results shown in Fig.3 were obtained by heating the Bragg grating using a Peltier heat pump. The temperature sensitivity of the Bragg grating was measured to be -0.95 KHz/°C, in terms of RF frequency shifts, a value in close agreement with the value expected.[3] Clearly similar results are expected if the in-fibre grating were to be stretched (-0.098 KHz/$\mu\epsilon$[1]) or pressurised (0.26 KHz/MPa[3]), provided the same AOTF is used at same wavelength.

3.0 The OTDR system for extended gauge-length measurements

The grating interrogation systems described so far allow the multiplexed sensing of strain at a number of discrete points in a fibre. However, for many sensing applications, it is desirable to have a system able to monitor the average strain over a longer length of the structure. This is being attempted in our programme using a specially-designed high-resolution optical time domain reflectometer. This will enable us to determine the optical path length between partially-reflected gratings along the fibre.[11]

Our proposed system is shown in Fig.4. The details of our OTDR will be published at a later date. The system will allow us to determine the optical range of each grating from the "pulse-echo" delay, from which changes in length in each intervening fibre section can be determined. The system is currently undergoing free-space tests using a laser source, with mirrors to emulate the gratings. In the near future we expect to conduct guided-wave tests to interrogate optical fibre sensing sections

4.0 Conclusions

We have demonstrated an attractive method for the interrogation of a Bragg grating sensor using an acousto-optic tunable filter. Although in our first experiment, this was for thermal monitoring, strain or pressure measurement should, of course, be possible. This technique offers considerable advantage over previous approaches. In particular the method has the potential for frequency-agile access, wide tuning range, and the ability to recover after transient signal loss etc., all of which are likely required in practical multiplexing applications. The system developed is therefore likely to provide a practical means for interrogating multiplexed in-fibre Bragg grating sensors.

In addition to the point-sensor interrogation system we are currently developing an OTDR system for long gauge length sensing which we hope to report in more detail in a future publication.

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