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Demultiplexing of fibre Bragg grating temperature and strain sensors

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Abstract

We describe a demultiplexing scheme for fibre optic Bragg grating sensors in which signal recovery is achieved by locking each sensor grating to a corresponding receiver grating. As a demonstration, the technique is applied to strain and temperature sensing, achieving a resolution of 3.0 $\mu\epsilon$ and 0.2°C, respectively.

1. Introduction

Fibre optic Bragg gratings are attracting considerable interest as sensing elements in quasi-distributed sensors [1,2]. They may be formed by illuminating germania doped fibres from the side with a periodically varying intensity pattern. The resulting refractive index grating then reflects at the wavelength, $\lambda = 2nD$ where n is the mode refractive index and D is the grating period. Placing the fibre under strain or subjecting it to a change of temperature causes nD and therefore λ to change. By determining the wavelength of peak reflectivity the strain or temperature to which the fibre is subjected may be found.

Encoding the sensed information in wavelength form has several distinct advantages over direct intensity based sensing schemes. Most important is that wavelength is an absolute parameter and so does not

depend on losses in the system or source power.

Possible applications proposed for Bragg grating sensors include the monitoring of body temperature for medical purposes and monitoring of strain in composite materials, which are increasingly being used in avionic structures. The small size and dielectric properties of the optical fibre lends itself readily to such uses. For these applications, information is needed at many points so gratings need to be written along the fibre. In order to interrogate the output signals from a serial array of grating sensors it is necessary that each sensor be uniquely identified by the wavelength of maximum reflectivity. This can be achieved in principle if each of n grating sensors has a specified and non-overlapping working range $\Delta\lambda_1, \Delta\lambda_2, \dots, \Delta\lambda_n$. If now the system is illuminated by a broad band source with a bandwidth greater than $(\lambda_1 - \lambda_n)$ then the back reflected signal will consist of n components where the central wavelength of each component is directly related to the measurand it is designed to monitor.

The strain information can in principle be recovered using an optical spectrum analyser but the

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cost, size, weight and frequent need to recalibrate the instrument makes this unattractive for some applications. An interrogation scheme based upon a Mach Zehnder interferometer acting as a wavelength discriminator has been reported by Kersey et al. [3]. This approach offers very high performance for a single sensor but it is not well suited to the multiplexing of a large number of sensors without employing time division multiplexing (TDM).

Recently a novel approach to demultiplexing the output signal from a sensor array has been proposed where a receiver grating is matched to a corresponding sensor [4]. The sensor receiver grating pair is shown in Fig. 1. Light from the broad band source (BBS) is launched into the sensing fibre where it is back reflected from the sensor grating, passing via the directional coupler to the receiver grating. Both gratings reflect at the same central wavelength when put under identical strains. The strain to which the sensor grating is subjected is found by scanning the central reflecting wavelength of the receiver grating, using the PZT, until their strains match and a signal is seen at the detector. The sensor strain can then be deduced from the voltage applied to the PZT. When several sensing gratings are required, each must have an associated receiver grating.

In the earlier work [4] the receiver gratings were placed in parallel, each with its own detector and this configuration was demonstrated with a simple two sensor system in which the receiver gratings were repeatedly scanned and a periodically varying strain applied to each sensor was recovered.

There are considerable advantages to be gained if the sensor/receiver grating pairs are locked together using a servo control system as shown in Fig. 1. Firstly, since light is always being received by the de-

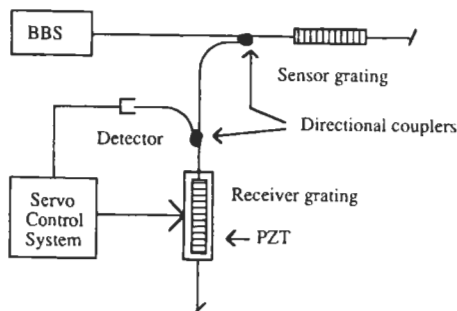


Fig. 1. The sensor-receiver grating pair.

detector, the signal to noise ratio is considerably improved. Secondly, the receiver gratings may be placed in series and only one detector is required with the advantage over the parallel arrangement that only one coupler is used and therefore power losses are kept to a minimum.

In this paper we describe a two sensor system with serial receiver gratings and servo control systems which lock together each sensor/receiver grating pair. The system is demonstrated as both a temperature and strain sensor.

2. Experiment

The two sensor system is shown in Fig. 2. The network was illuminated by a Ti:sapphire laser pumped superfluorescent erbium doped fibre source with a bandwidth of 17 nm centred around 1.55 μm and a bandwidth of 5 nm centred around 1.536 μm . The total power reaching the sensor was about 4 mW. The two grating pairs reflected at centre wavelengths of 1549.9 ± 0.1 nm and 1534.8 ± 0.1 nm in the unstrained case, with a bandwidth of 0.2 nm.

The response of the combined sensor-receiver pair is the convolution of their individual responses. An AC modulation of 86Hz was applied to the PZT which strains receiver grating G'1. This has the effect of

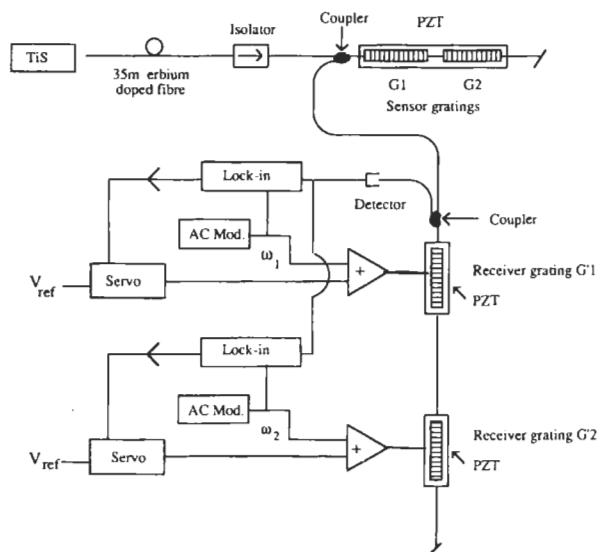


Fig. 2. Experimental arrangement for the servo controlled simple multiplexing scheme.

producing an AC signal at the detector, the amplitude of which is proportional to the derivative of the convolved response.

Initially the servo-control systems were disconnected and the output from the lock-in monitored as the voltage controlling the sensor G1 PZT was increased. The results are shown in Fig. 3. The servo-control system was then connected and the reference voltages V_{ref} adjusted to cause the receiver grating to lock to the centre of the transfer function as indicated in Fig. 3. Once the system had been set up in this way, any variation in the sensor grating strain was mirrored by a corresponding change in the receiver grating PZT voltage.

A similar procedure was followed for the other sensor/receiver grating pair except that the receiver PZT was modulated at a frequency of 62 Hz. Using a different modulation frequency for each receiver grating is necessary in order to distinguish the signals from each grating pair when a single detector is employed.

The relationship between sensor and receiver grating PZT voltages is shown in Fig. 4. The relationships deviate from linearity due to the hysteresis of the PZTs. This hysteresis effect can be avoided in a practical system by using position feedback PZTs. As an indication of the resolution possible, the most linear region of the data in Fig. 4, consisting of ten points, gave an rms deviation from linearity of 0.7 V corresponding to a strain resolution of $2.8 \mu\epsilon$ (micro-strain).

In a second experiment, the sensor gratings were placed in an oven to monitor how the receiver grating PZT voltages depended upon sensor temperature. The

results are shown in Fig. 5. These values represent an upper limit to the achievable resolution of the system; better results are likely to be obtained using PZTs incorporating feedback. The rms deviation from linearity of the data for grating pair 1 is 0.5°C and for grating pair 2, using the most linear region of the graph consisting of 17 points, the linearity is 0.2°C .

These data were all taken for a gradually decreasing sensor temperature. The nonlinearity evident in the data for grating pair 2 is thought to be caused by the hysteresis in the PZTs described earlier.

Both experiments reported here have involved the measurement of slowly varying quantities and are therefore limited by the presence of $1/f$ noise within the system. To obtain a measure of the capability of the system when used with periodic signals a sinusoidal signal with a frequency of 86 Hz was applied to the PZT holding receiver grating G'1 so as to produce a periodically varying strain with an amplitude of $104 \mu\epsilon$. The signal received by the detector was monitored with a spectrum analyser which showed the signal to noise ratio to be 64 dB in a 0.955 Hz bandwidth. From this we estimate that the noise limited resolution of the system at 86 Hz is $67 \text{ n}\epsilon/\sqrt{\text{Hz}}$.

The technique presented here allows simultaneous signal recovery from a number of sensors. The number of grating sensors which can be deployed on the fibre depends upon the maximum strain level or temperature range to be measured. For a strain of $1 \text{ m}\epsilon$, the change in the Bragg wavelength is 1.15 nm [5]. With a source bandwidth of 22 nm up to 19 sensors could be deployed on the fibre, each measuring up to $1 \text{ m}\epsilon$. When used as a temperature sensor, the change

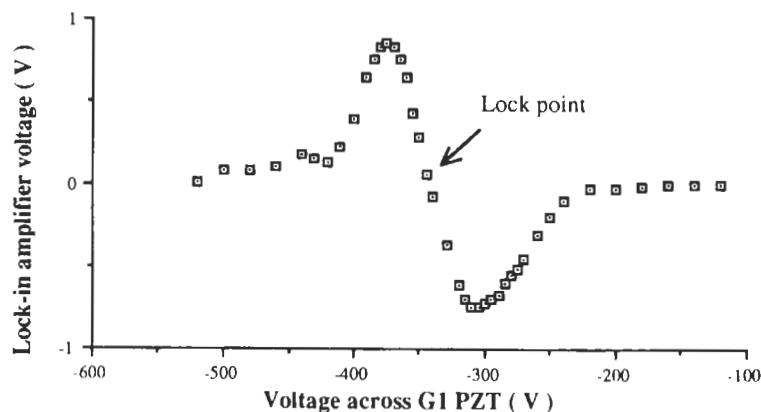


Fig. 3. Lock-in amplifier output when the detector grating is oscillated and the sensor grating is slowly scanned.

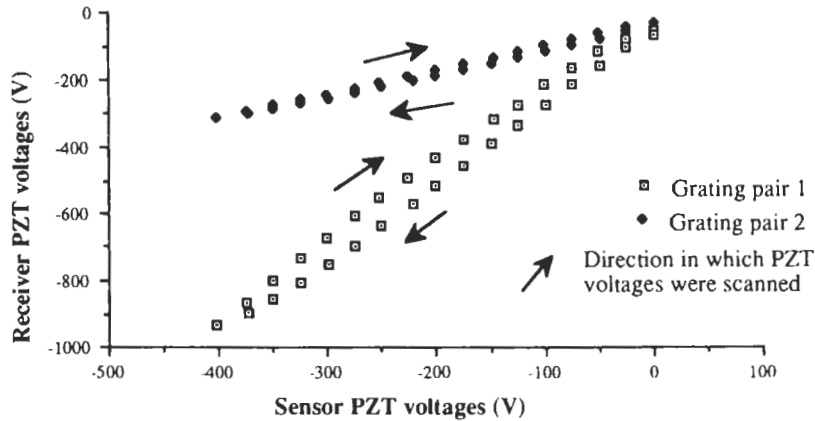


Fig. 4. Relationship between the sensor and receiver grating PZT voltages when they are locked together.

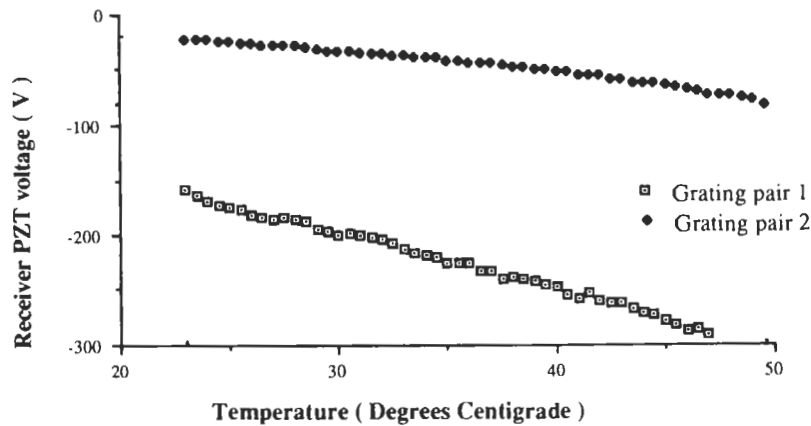


Fig. 5. The relationship between the receiver grating PZT voltages and sensor temperature.

in the Bragg wavelength is $1.3 \times 10^{-2} \text{ nm}/^\circ\text{C}$ [5]. So with the same source bandwidth 10 sensors each with a range of 170°C could be addressed.

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References

- [1] G. Meltz, W.W. Morey and W.H. Glenn, *Optics Lett.* 14 (1989) 823.
- [2] W.W. Morey, G. Meltz and W.H. Glenn, *SPIE vol. 1169 Fiber Optic and Laser Sensor VII* (1989) pp. 98-107.
- [3] A.D. Kersey, T.A. Berkoff and W.W. Morey, *Proc. of 1st European Conf. on Smart Structures and Materials* (Glasgow, England, 1992) pp. 61-67.
- [4] D.A. Jackson, A.B. Lobo Ribeiro, L. Reekie and J.L. Archambault, *Optics Lett.* 18 (1993) 1192.
- [5] W.W. Morey, J.R. Dunphy and G. Meltz, *SPIE vol. 1586* (Boston, 1991) pp. 216-224.