Bragg grating temperature and strain sensors.

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INTRODUCTION

Fibre optic Bragg gratings are attracting considerable interest as sensing elements in quasi-distributed sensors.[1,2] The grating takes the form of a periodically varying refractive index written into germania doped fibres to reflect light at a wavelength $\lambda=2nD$ where n is the mode refractive index and D is the grating period. The reflected wavelength changes when the fibre is placed under strain or subjected to a change in temperature so the grating may be used as a sensor.

Many gratings may be written at arbritrary locations in the fibre so strain or temperature can be monitored at chosen discrete points over large distances. Possible applications include monitoring body temperature for medical purposes or the strain in composite materials which are used in avionic structures. The small size and dielectric properties of the fibre makes grating sensors particularly suited to these uses.

Encoding the sensed information in wavelength has several advantages over intensity based schemes, primarily that sensing accuracy is not affected by losses in the system.

To interrogate a large serial array requires that each grating operates in its own wavelength range. The information can then be recovered in principle using an optical spectrum analyser but the cost, size, weight and need to recalibrate the system makes it unsuitable for some purposes. Kersey et al[3] have reported an interrogation scheme which uses a Mach Zehnder interferometer as a wavelength discriminator. This gives high performance for a single grating but is not well suited for interrogating a large serial array without employing time division multiplexing (TDM).

A novel interrogation scheme has been proposed where another grating is used to monitor the wavelength from the sensor grating [4]. Light from a broad band source (BBS) is launched into the sensing fibre where it is back-reflected from the sensing grating and passes via a directional coupler to a receiver grating. Any signal back-reflected from the reveiver grating passes via another directional coupler to a detector. The two gratings reflect at the same central wavelengths when unstrained. A known strain is applied to the receiver grating using a PZT. This strain equals the strain the sensor is under when a peak signal is seen at the detector. When several sensing gratings are required, each must have a corresponding receiver grating.

In 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.

In the work reported here the sensor receiver / grating pairs are locked to each other using a servo-control system. Light is then always received by the detector giving a high signal to noise ratio. The receiver gratings are also placed in series so only one detector is required and only one coupler is used so 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.

EXPERIMENT

The two sensor system is shown in figure 1. The network was illuminated by a Ti:sapphire laser pumped superfluorescent erbium doped fibre source with a bandwidth of 17nm centred around 1.55µm and a bandwidth of 5nm centred around 1.536µm. The total power reaching the sensor was about 4mW. The two grating pairs reflected at

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centre wavelengths of 1549.9±0.1nm and 1534.8±0.1nm in the unstrained case, with a bandwidth of 0.2nm.

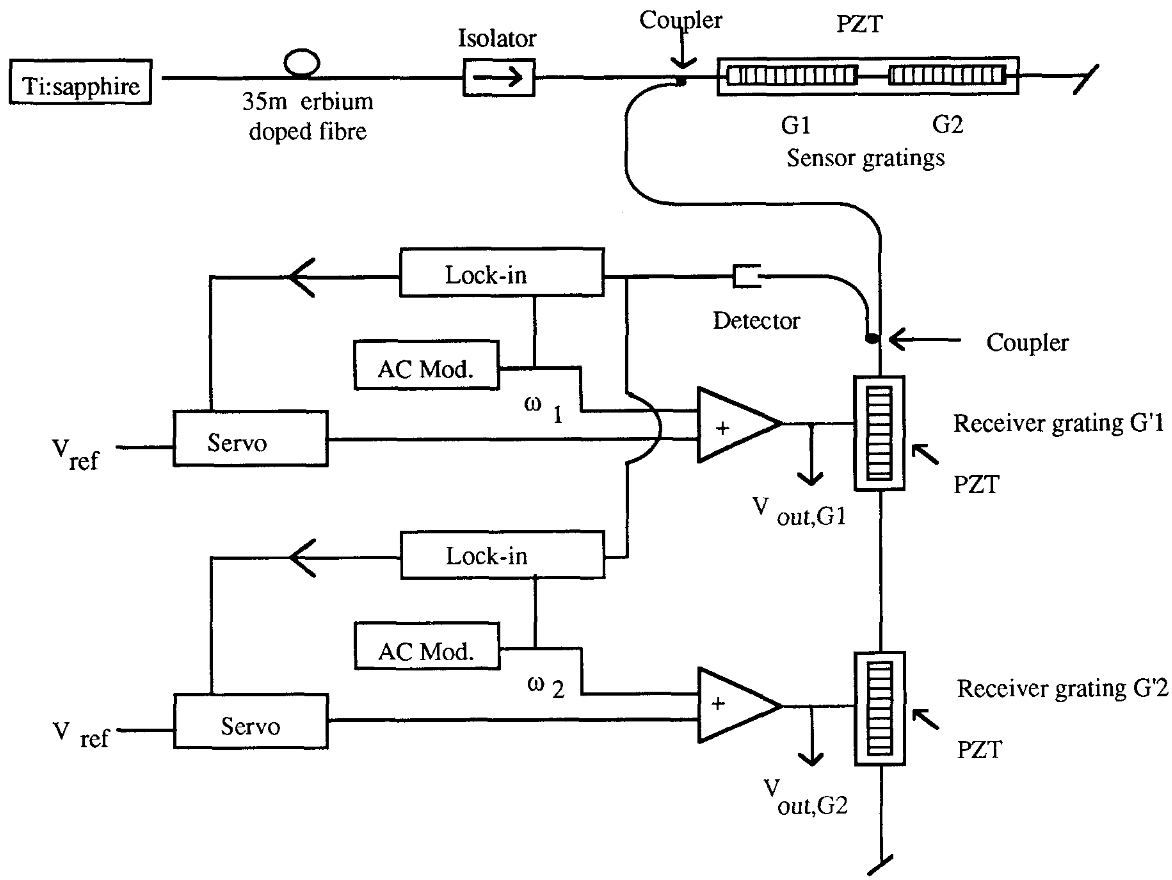

Figure 1 Experimental arrangement for the servo controlled simple multiplexing scheme.

The locking is achieved by modulating the strain of the receiver grating relative to the sensor gratings. The response of the combined sensor receiver grating pair is the convolution of their individual responses. Modulating the receiver grating produces an AC signal at the detector, the amplitude of which is proportional to the derivative of the convolved response. This is shown in figure 2 for grating pair 1 with a modulation of 86Hz, obtained by disconnecting the servo-control system and monitoring the output of the lock-in amplifier as the voltage controlling the sensor G1 PZT was increased.

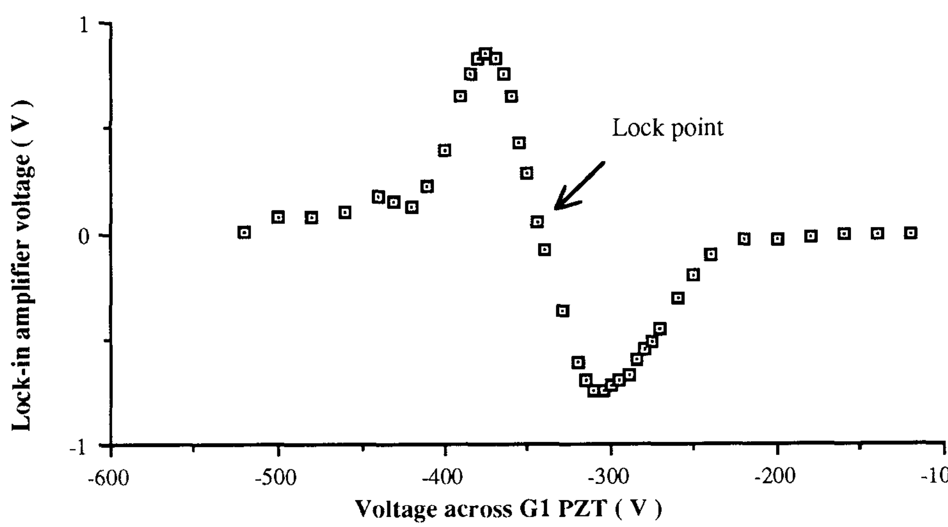

Figure 2 Lock-in amplifier output when the detector grating is oscillated and the sensor grating is slowly scanned.

The gratings are locked to each other by connecting the servo-control system and setting the reference voltages

Vref to cause the receiver grating to lock to the centre of the transfer function as indicated in figure 2. Once the system is set up in this way, any variation in the sensor grating strain is mirrored by a corresponding change in the receiver grating PZT voltage.

A similar procedure was followed for the G2 pair but the modulation frequency was 62Hz, chosen to be different in order to distinguish the signals from each grating pair when a single detector is employed.

The sensor PZT voltages were scanned and the servo-control system adjusted the voltages of the receiver grating PZTs, the results being shown in figure 3. The relationships deviates from linearity due to PZT hysteresis. This effect can be avoided in a practical system by the use of position feedback PZTs. As an indication of the resolution possible, the most linear region of the data in figure 3 for grating pair G2 consisting of ten points, gave an rms deviation from linearity of 0.7V corresponding to a strain resolution of 2.8με (micro-strain).

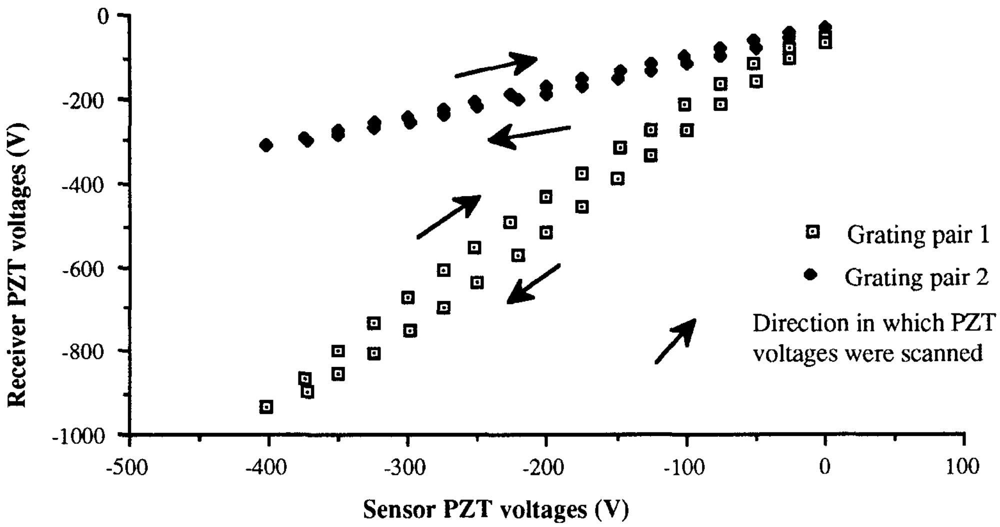

Figure 3 Relationship between the sensor and receiver grating PZT voltages when they are locked together.

To test how well the sensor gratings monitor temperature they were placed in an oven. The results are shown in figure 4. The rms deviation from linearity of the data for grating pair 1 is 0.5^{o}C and for grating pair 2, using the most linear region of the graph consisting of 17 points, the linearity is 0.2^{o}C. These values represent an upper limit to the achievable resolution of the system; better results are likely to be obtained as in the previous case if PZTs incorporating feedback are used.

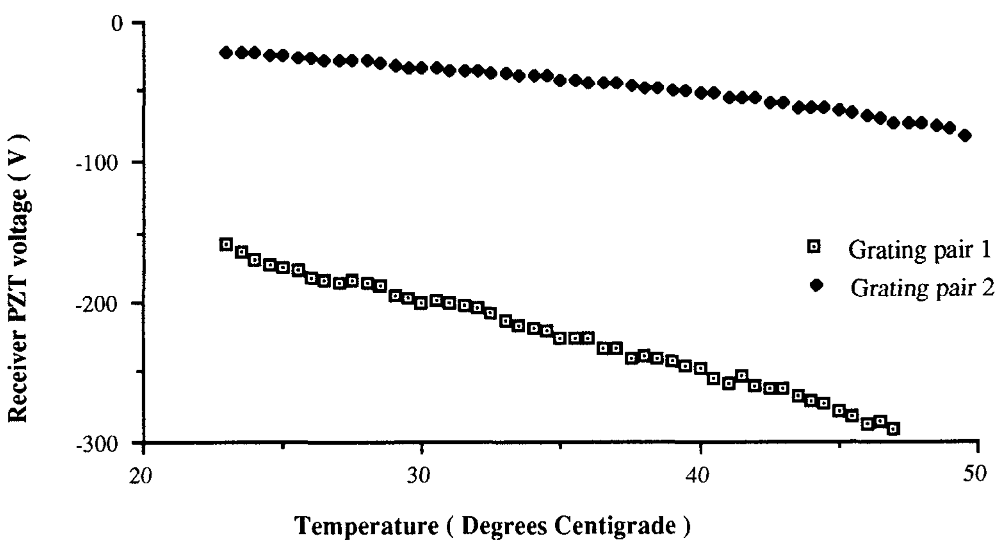

Figure 4 The relationship between the receiver grating PZT voltages and sensor temperature.

These data were all taken for a gradually decreasing sensor temperature. The non-linearity 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 qualities 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 86Hz was applied to the PZT holding receiver grating G'1 so as to produce a periodically varying strain with an amplitude of 104με. The signal received by the detector was monitored with a spectrum analyser which showed the signal to noise ratio to be 64dB in a 0.955Hz bandwidth. From this we estimate that the noise limited resolution of the system at 86Hz is 67nε/√Hz.

The use of a Ti :sapphire laser and erbium doped fibre to power the system is unsuitable for some applications due to size and cost. An LED is more practical. The strain experiment has been repeated using a 1.55μm ELED (OK1-506G) source with a bandwidth (FWHM) of 70nm which is able to launch a power of 10 μW into a single mode fibre. The results are shown in figure 5. The rms deviation from lineraity for data below the sensor PZT voltage of -300V suggests a resolution of 8.3με. The noise limited resolution of the system using an ELED is 2.7με/√Hz at 86Hz.

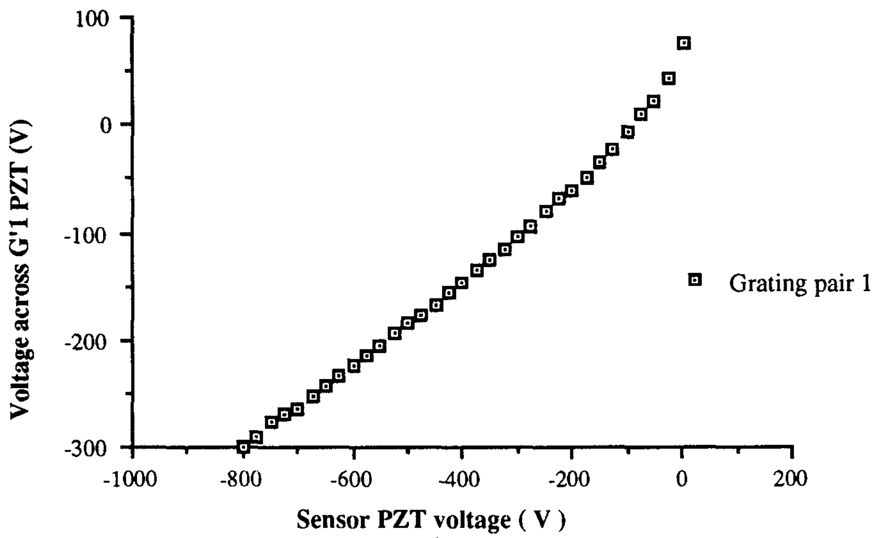

Figure 5 Relationship between the sensor and receiver grating G1 PZT voltages when they are locked together and a ELED is the source.

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 1mε, the change in the Bragg wavelength is 1.15nm [5]. With a source bandwidth of 22nm up to 19 sensors could be deployed on the fibre, each measuring up to 1mε. When used as a temperature sensor, the change in the Bragg wavelength is 1.3×10^{-2} nm / ^{o}C [5]. So with the same source bandwidth 10 sensors each with a range of 170 ^{o}C could be addressed.

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