Tu2.6

SIMULTANEOUS INTERROGATION OF FIBRE OPTIC GRATING SENSORS

D.A. Jackson and A.B. Lobo Ribeiro*

Physics Laboratory, University of Kent, CANTERBURY, Kent. CT2 7NR, UK.

L. Reekie, J.L. Archambault and P.St. Russell
ORC, University of Southampton, SOUTHAMPTON, Hants. SO9 5NH.

INTRODUCTION

Fibre optic Bragg gratings(1) are attracting considerable interest for application as sensing elements in distributed sensors. As the grating sensors can be 'written' in series at any arbitrary location along a fibre without inducing any changes in the fibre dimensions, it can be readily incorporated into complex structures, such as composites without compromising the structural integrity. In this type of application the gratings will be written at specific positions along the fibre such that when it is incorporated into the structure each sensing element will be located at a critical monitoring point. For capital items such as passenger aircraft, for example, a large number of sensors will be required.

In order to interrogate and demultiplex the output signals from a serial array(2) of grating sensors it is necessary that each sensor can be uniquely identified from the wavelength where it has maximum reflectivity. This can be achieved in principle if each grating sensor has a specified working range $\Delta\lambda_{1s}, \Delta\lambda_{2s}, \ldots\Delta\lambda_{ns}$, where $\Delta\lambda_{1s} = (\lambda_1 - \lambda_2)$; $\Delta\lambda_{2s} = (\lambda_2 - \lambda_3)$, and $\Delta\lambda_{ns} = (\lambda_{n-1} - \lambda_n)$ and the instantaneous central reflecting wavelength of each grating sensor falls between $\Delta\lambda_{1s}$, $\Delta l_{2s} \ldots\Delta\lambda_{ns}$,etc. If now the system is illuminated with a broad band source with a bandwidth $\geq (\lambda_1 - \lambda_n)$ then the back reflected signal will consist of (n-1) frequency components where the central wavelength of each component is directly related to the length of each grating reflector and hence the current value of the measurand it is designed to monitor. Measurement of a large number of wavelengths with high precision is possible using costly instruments such as optical spectrum analyzers, however this is not feasible in a practical application due to the size, weight and frequent need to recalibrate the instrument. Recently, 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 is not easy to use for multiplexing a large number of sensors without incorporating time division multiplexing (TDM). Here we present a novel approach for multiplexing the output signals from a network of grating sensors, which allows virtually simultaneous interrogation of all the sensors, based upon matching a receiving grating to a corresponding sensor.

The basic concept of the 'sensor-receiver' grating pair is shown in figure 1. Light from the broad band source (BBS) is transferred to G_{1S}, the grating sensor, via the directional coupler, light back reflected from G_{1S} then propagates back through the fibre network to the receiving grating, G_{1R}, which is mounted on a piezoelectric stretcher. G_{1R} is fabricated such that its central reflecting wavelength is identical to G_{1S} when both gratings are subject to the same stress. When G_{1S} is deployed as a sensor its central reflecting wavelength will vary randomly and will generally not match that of G_{1R}. If now the central reflecting wavelength G_{1R} is linearly swept

---

* INESC - Optoelectronics Group, Rua José Falcão, 110, 4000 PORTO, Portugal.

Reprinted with permission from the 9th Optical Fiber Sensors Conference, Associazione Elettrotecnica ed Elettronica Italiana (Florence, 1993).

over $\Delta\lambda_{1S}$ by driving the PZT stretcher then at one point in the sweep the reflecting wavelengths of G_{1S} and G_{1R} will exactly match, for this condition a strong signal will be back reflected from G_{1R} and detected by the photodiode. Given that the voltage to wavelength coefficient of G_{1R} is known then the instantaneous value of the length of G_{1S} can be determined. This simple approach allows both the absolute length of G_{1S} to be determined and its variations. An alternative method of signal recovery, also indicated in figure 1, would be to use a closed loop servo to maintain the 'matched' condition. As shown in figure 2 it is very straightforward to extend this arrangement to a multiplexing topology. Here the receiving gratings are deployed in parallel, where the receiving gratings, G_{1R}, G_{2R}, G_{3R}, G_{4R}, are individually matched to their corresponding sensing gratings, G_{1S}, G_{2S}, G_{3S}, G_{4S}, when subject to identical stresses. The receiving gratings are now all mounted on the same PZT which is driven linearly (or sinusoidally) such that all grating pairs will match once per cycle, enabling the lengths of G_{1S} ..... G_{4S} to be simultaneously determined at a high data rate.

The number of grating sensors which can be deployed on the fibre depends on the maximum strain level to be measured and the dynamic range of each sensor; for a typical application a resolution of 1 $\mu\varepsilon$ (micro-strain) with a range of 1 mε would be adequate, for silica fibre at 1.55 μm, the change in the Bragg wavelength is 10^{-3} nm/$\mu\varepsilon$, hence for $\Delta\lambda_s$ of 1 nm, with a source with a bandwidth of 50 nm, up to 50 sensors could be deployed on the fibre. If a larger number of sensors are required then several fibres with a similar number of sensors could be deployed with TDM used to sequentially interrogate each serial network of sensors. The resolution of each grating-receiver pair depends critically on the linewidth of the gratings.

EXPERIMENTAL

A network comprising two sensor-receiving grating pairs was used to demonstrate the feasibility of the multiplexing approach described above. The network was illuminated with a 1.55 μm ELED source with bandwidth (FWHM) of 70 nm supplied by OKI, the launched power was ~10 μwatts. The grating pairs were induced into the fibres by illuminating the fibre from the side with a variable spacing fringe pattern produced using a bulk interferometer illuminated with an Eximer laser(1). The Bragg wavelengths of the grating pairs were 1549.0 ± 0.1nm and 1534.8 ± 0.1nm with bandwidths of 0.2nm. The experimental arrangement is shown in figure 3; where the grating sensors G_{1S} and G_{2S} are mounted on separate PZT strechers and the receiving gratings, G_{1R} and G_{2R} are mounted on the same PZT strecher (PZT_R).

In order to establish the multiplexing capability of the system sensors G_{1S} and G_{2S} were modulated at frequencies of 62 and 85 Hz. The output signals from D1 and D2 were then coupled into separate channels of a spectrum analyzer and the receiving grating pair were swept over their respective ranges by driving PZT_R, with a triangular voltage ramp. The resulting spectra are shown in figure 4 where the output signals from each grating are shown, the S/N ratio for both sensors $\approx$ 25 dB in a $\approx$ 0.4 Hz bandwidth equivalent to $\approx$ 16 dB/$\sqrt{\text{Hz}}$. The spectra also shows there is no discernible cross-talk between sensors. The linearity and resolution of the technique was measured for quasi-static signals by varying the length of G_{1S}; by changing the voltage applied to PZT_{1S}, and then adjusting the value of the voltage on PZT_R to maximize the output signal. This data is shown in figure 5, which as expected shows a linear relationship, the minimum detectable strain was 4.16 $\mu\varepsilon$ (micro-strain). As the input power was relatively low these measurements were performed with the ELED amplitude modulated at 1kHz such that AC signal recovery could be used. The system was also used to demodulate the output of the grating sensors when they were driven with periodic signals. The results of this experiment are shown in figure 6, where the amplitudes of the side bands at 1 kHz show that the grating is being periodically strained at 20 Hz at an amplitude of 594 $\mu\varepsilon$.

SUMMARY

A new multiplexing scheme has been proposed and demonstrated for Bragg grating sensors. This technique allows virtually simultaneous signal recovery from a large number of sensors with very low cross-talk. The technique is demonstrated for both quasi-static and periodic measurands. The resolution achieved of 4.12 $\mu\varepsilon$ was dictated by the linewidth of the grating, recently we have produced gratings with a linewidth of 5×10^{-2} nm which should improve the resolution to ≈ 1 $\mu\varepsilon$ (micro-strain).

Acknowledgements: A.B.L.R. would like to acknowledge the financial support of the Optoelectronics Group of INESC, Porto, Portugal and the Treaty of Windsor, D.A.J., L.R. and J.L.A. also acknowledge support from the SERC (U.K.).

REFERENCES

(1) G. Meltz, W.W. Morey and W.H. Glenn, "Formation of Bragg gratings in optical fiber by a transverse holographic method", Optics Lett., **14**, 823, 1989.
(2) W.W. Morey, "Distributed Fiber Grating Sensors", Proc. OFS'90, p.285, Sydney, Australia, Dec. 1990.
(3) A.D. Kersey, T.A. Berkoff and W.W. Morey, "Fiber-grating based strain sensor with phase sensitive detection", 1st European Conf. on Smart Structures and Materials, p.61, Glasgow, England, 1992.

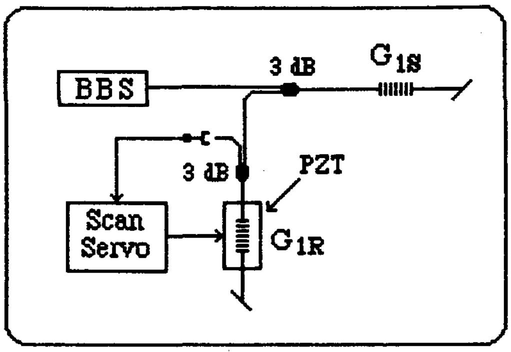

Figure 1. Basic concept of sensor receiving grating pair.

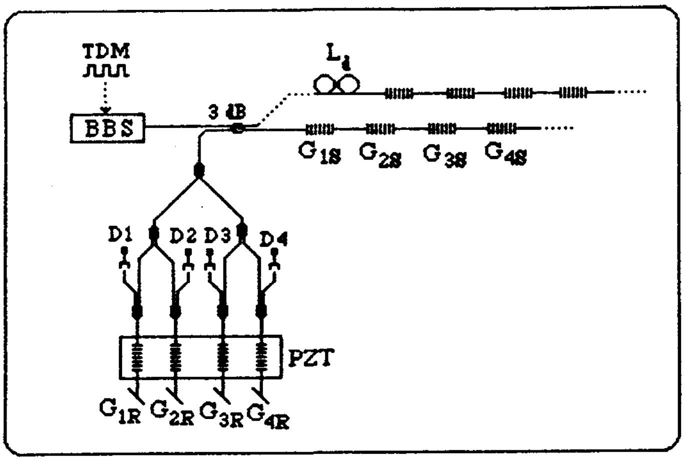

Figure 2. Expansion of the arrangement shown in fig.1 to enable multiplexing of a large number of grating sensors. The number of sensors can be increased by incorporating additional sensing fibres with TDM, (the source is then pulsed).

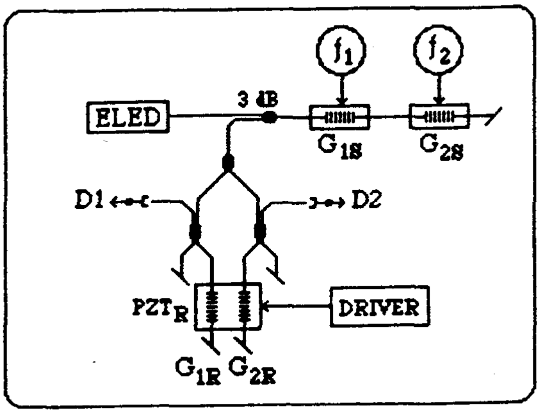

Figure 3. Experimental system with two sensor-receiving grating pairs.

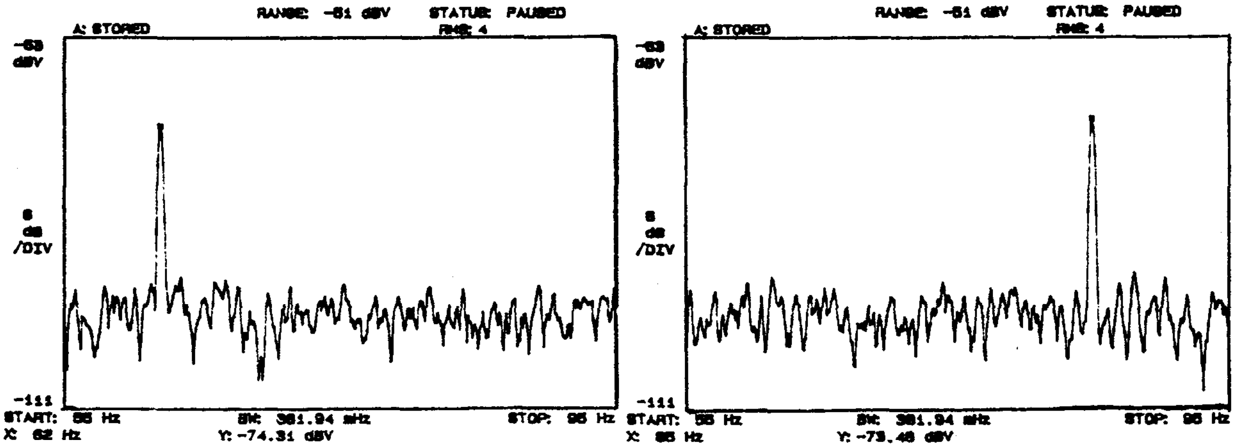

Figure 4. Ouput spectra recorded as PZR_R in linearly swept, when sensors G_{1S} and G_{2S} are driven at 62 Hz and 85 Hz respectively.

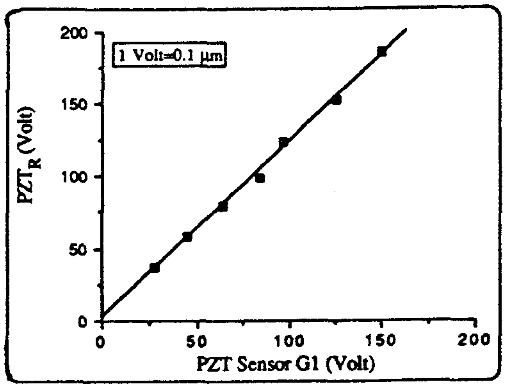

Figure 5. Variation of matching voltage PZR_R as a function of the driving voltage applied to G_{1S}.

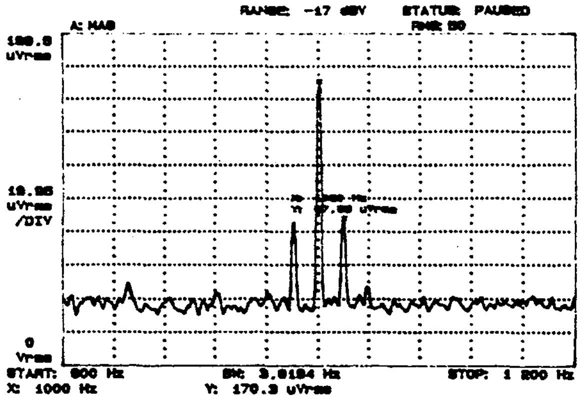

Figure 6. Ouput spectrum from G_{1S} when it is subject to periodic strain (the intensity of the source is modulated at 1 kHz).