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OPTICAL FIBRE PRESSURE AND STRAIN SENSORS FOR SMART STRUCTURES

J.P. Dakin, M.G. Xu and L. Reekie

Optoelectronics Research Centre (ORC)
University of Southampton
Highfield, Southampton
SO9 5NH, UK

ABSTRACT

The paper describes a number of optical-fibre-based pressure sensing methods. These are intended for ultimate application as strain sensors for composite materials but will have application as pressure sensors in their own right. In addition, an architecture for a multiplexed strain sensing system will be described.

INTRODUCTION

Optical fibre sensors have many advantages for monitoring strain in composites and these are listed below:-

(i) Silica is an excellent elastic material, largely free from creep and fatigue problems.
(ii) Total immunity to electromagnetic interference and lightning strike, etc.
(iii) 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.

Prior to testing a number of optical sensors for suitability for strain measurement, we have conducted tests under the simpler influence of isotropic pressure. The pressure is conveniently applied via hydraulic fluid.

In parallel with the above activity, we are also examining an architecture for a multiplexed sensing system. The applications of this are described in a paper in this same meeting/1/.

1. THE OPTICAL FIBRE PRESSURE SENSORS

Three types of optical fibre pressure sensor have been constructed and tested. Two operate as a result of the optical path changes which occur when an optical fibre is subjected to pressure (the changes result from pressure-induced changes in both the physical length of the fibre and in the refractive index of the material), whereas the third type uses a hollow glass microsphere as a sensing element/2/.

Of the two fibre based sensors, the first uses a length of conventional optical fibre as the sensing element. Light from an LED source is split along two optical fibre paths, and then these paths are recombined. Only one of these paths is pressurised, (see fig 1). The change in the optical path difference resulting from this pressure is detected by applying radio frequency modulation to the light source. At certain drive frequencies, the modulation of the two signals arriving at the detector via the two arms is in antiphase and then "nulls" in the modulation signal are observed. These nulls in the network response are conveniently observed by driving the optical source, using the output of an electronic network analyser. The response to pressure and temperature, when a multimode fibre sensor is used, are shown in Fig.1. The length of pressurised fibre was 152 m. For the strain measurement, a shorter length of fibre, of the order of 2 m, should suffice, because of the higher levels of strain which would apply.

Our second type of fibre based sensor is more suitable for short-gauge-length sensing. This type, however, requires the prior formation of a periodic change in refractive index, or "phase grating" in a short section of the fibre, by illuminating it with converging beams of UV light/3,4,5/. Such gratings form excellent miniature sensing regions (typically less than 1 mm length) which have been used to sense strain/6/, temperature/7/ and, more recently, hydrostatic pressure/8/. The wavelength of peak reflectivity of the grating can be measured as a function of pressure and temperature (Fig.2). A wavelength variation of 0.0031 nm per MPa was observed as the pressure was changed. In addition to pressure sensing, measurements of strain have been made, using such a grating embedded in a composite/1/ (these measurements were performed by Eaton of Westland Aerospace). The gratings produced by the Southampton University ORC have currently the best range of performance reported/4,5/ and therefore make excellent sensing elements.

The third type of pressure sensor uses a sensing element external to the fibre. Fabry-Perot (F-P) sensors have been reported for the measurement of strain, temperature, pressure, vibration and acoustic waves/9,10/. Several methods of creating extrinsic fibre-optic F-P interferometers have been described/11,12/. Fairly sophisticated separation methods are required in the probe head to maintain the mirror spacing, yet allow the sensor to be sealed against ingress of foreign material. In our method a hollow glass microsphere is bonded, in an on-axis position, to the end of a monomode optical fibre. A low finesse Fabry-Perot cavity is then formed between the sphere surfaces. The main advantages of our new arrangement is that the probe is simple, miniature and hermetically sealed. As with earlier F-P sensors/11,12/, the probe is conveniently addressed by monitoring its reflection spectrum. The wavelength of each peak reflection and the span between peaks are both dependent on the physical spacing between the reflective surfaces.

A schematic of the sensor construction is shown in Fig.3. Light from a 1550 nm fibre-pigtailed ELED is coupled into the sensor head via a directional fibre coupler. The sensing probe was tested within a cavity in a high pressure vessel, hydraulic pressure being applied to compress the sphere. The reflectance of the probe was monitored using a commercial optical spectrum analyser located to receive light form a return port of the coupler. Reflections from Fig.3 shows the reflected spectrum, observed in the wavelength domain, with a sensing probe fitted with a 120 μm diameter sphere of approximately 0.8 μm wall thickness. This spectrum shows a fringe spacing of 10 nm. The maximum intensity contrast of the fringes between peaks and minima of the reflected spectrum was 3.8 dB. The pressure response of the sensor is shown in Fig.3. This shows the variation of the wavelength of a particular reflection maximum (chosen to be 1552.47 nm at zero pressure) with pressure. The mechanical compliance of a hollow sphere is much higher than that of a solid body, such as a fibre or an in-fibre grating, so the fractional shift in wavelength with pressure is naturally much higher.

Measurements of the cross-sensitivity to temperature of our sensing probe, also shown in Fig.3, indicate that the errors due to temperature changes are relatively small. The measured temperature coefficient of wavelength variation was 0.0077 nm/°C. In particular, the ratio of the responses of the glass bubble to pressure and temperature were over two orders of magnitude better than we observed for the in-fibre-grating sensor.

2. MULTIPLEXED STRAIN SENSING

Our programme for multiplexed strain sensing is based on a series of in-fibre gratings in a length of fibre. We propose to measure the peak reflection wavelength of the gratings, using a multiplexed interrogation system and also to measure the distance between the gratings using an optical ranging system (precision guided-wave LIDAR system). The philosophy of our approach on this is presented in more detail in our co-published paper with Westland Aerospace, our collaborators on this activity/1/. We hope to present more details of our recent results on this system at the conference.

CONCLUSIONS

We have presented a number of recent developments in the field of optical fibre sensors. Some have been designed specifically for strain monitoring in composite material, but we have also presented several interesting results regarding their use as pressure sensors. The emphasis of our future work is to produce multiplexed sensor systems, capable of rapidly monitoring the strain in significant numbers of sensors.

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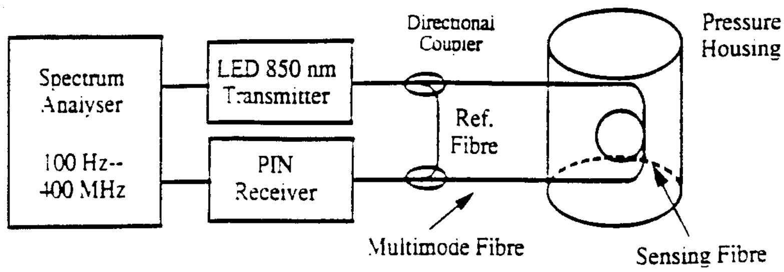
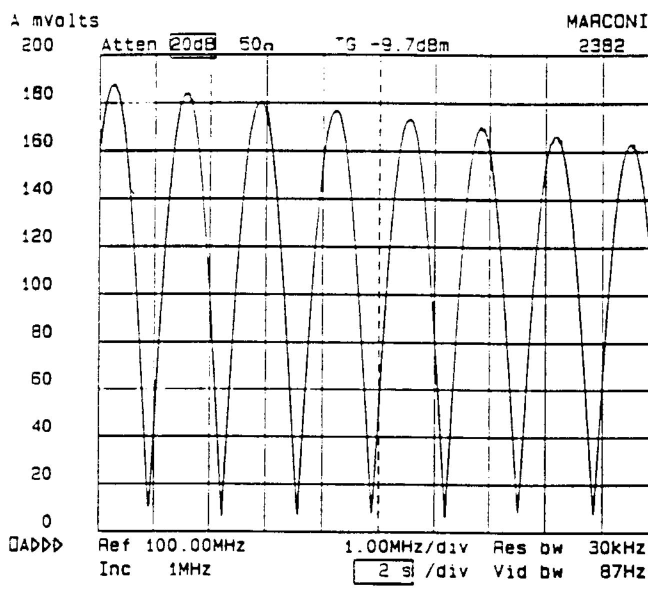
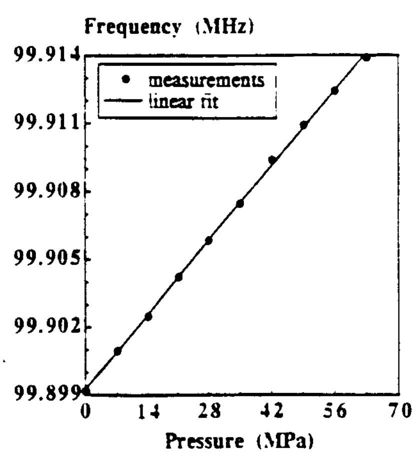


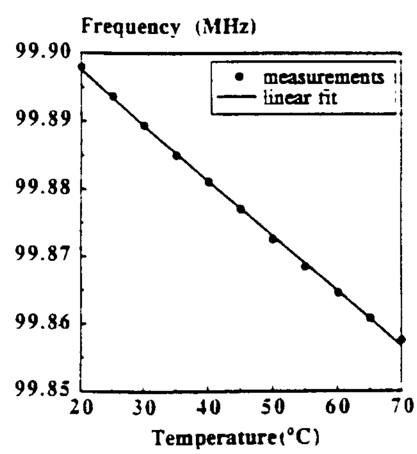
Schematic of pressure sensor based on
Mach-Zehnder interferometry



Transfer function (restricted bandwidth)

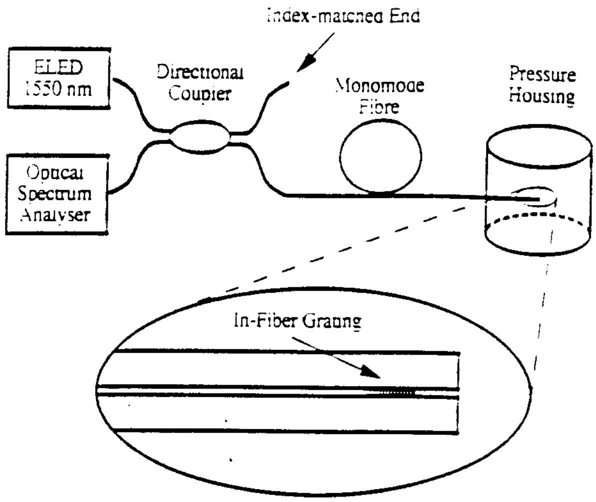


Pressure sensitivity

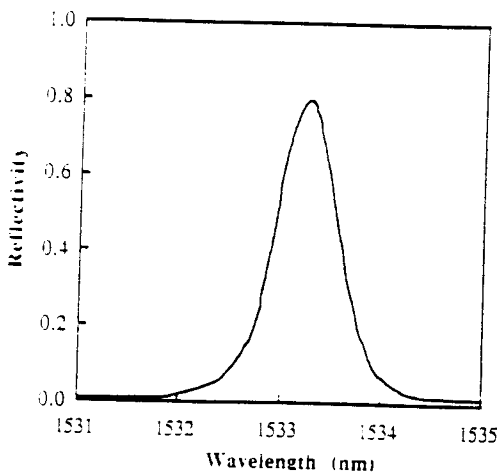


Cross-sensitivity

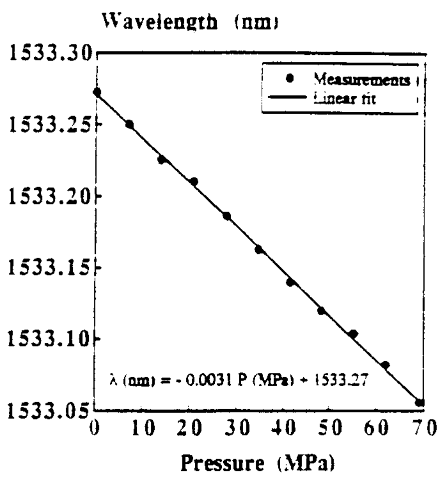
Fig 1 The Transversal Filter Pressure Sensor



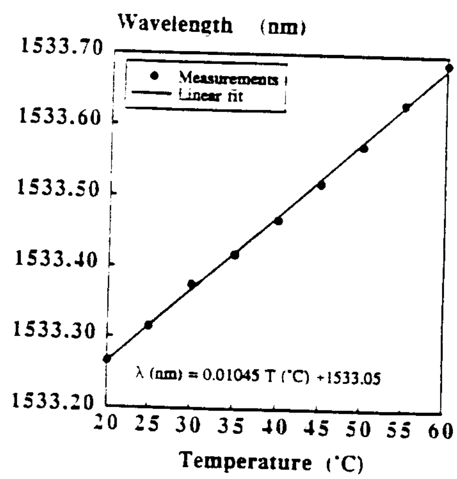
Schematic of the fibre grating pressure sensor



Reflected spectrum from in-fibre grating

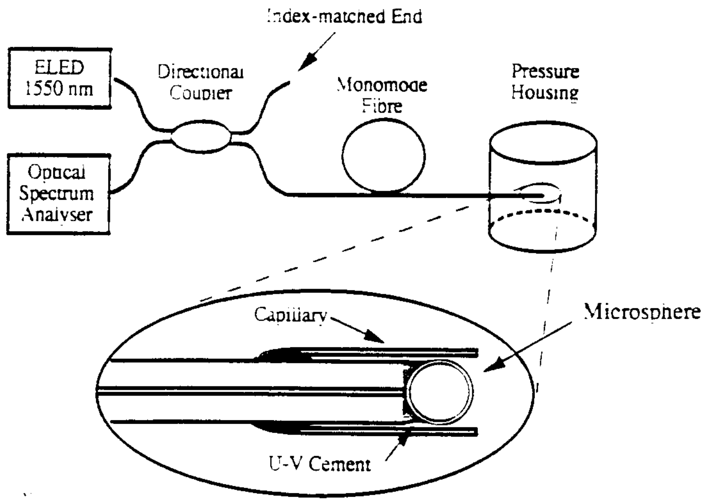


Pressure sensitivity of the in-fibre grating

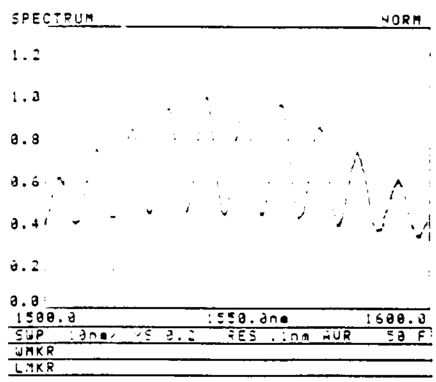


Temperature effect on in-fibre grating

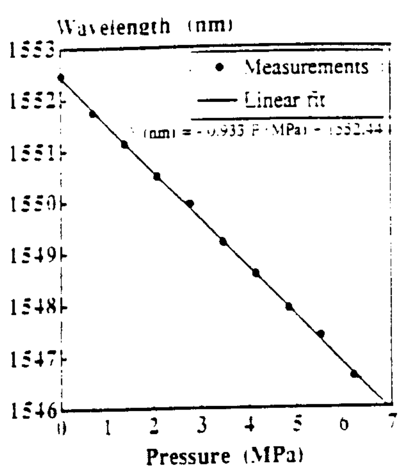
Fig 2 The Fibre Grating Pressure Sensor



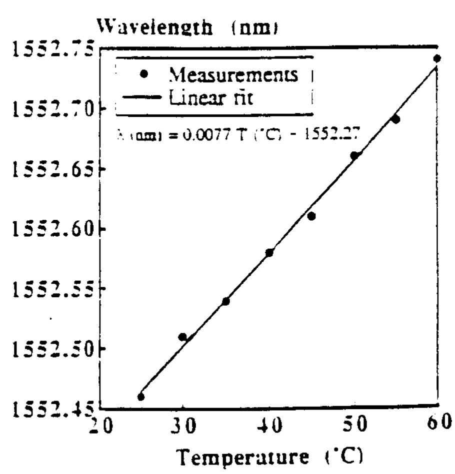
Schematic of the microsphere pressue sensor



Reflected spectrum from microsphere



Pressure sensitivity of the microsphere sensor



Temperature sensitivity of the microsphere

Fig 3 The Hollow-glass Microsphere Pressure Sensor