High Birefringence Fibre Interrogating Interferometer for Optical Sensing Applications

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ABSTRACT

We describe the use of high birefringence fibre forming a differential path interferometer for heterodyne fibre optic sensing applications. We firstly recover a low frequency strain amplitude of 1με at 1Hz applied to a fibre Bragg grating sensor demonstrating a noise limited resolution of around 100nε/√Hz. Secondly we interrogate a Mach-Zehnder interferometer sensor using the dual wavelength technique to detect a change in the Mach-Zehnder OPD of 200μm.

Keywords: High Birefringence Fibre, Interferometer, Sensor, Interferometric, Fibre Optic Sensing

1. INTRODUCTION

Interferometric techniques are usually used when it is important to obtain the highest resolution in an optical sensing system. An interferometer can be used as part of the signal processing scheme to address both interferometric [1] and fibre Bragg grating [2] sensors. In many such applications an optical path difference of a few hundred microns is a typical requirement.
From a technical point of view, an excellent way of implementing this is to use an integrated optic based Mach-Zehnder interferometer. Unfortunately this usually requires a bespoke, and therefore very expensive, device, which does not facilitate

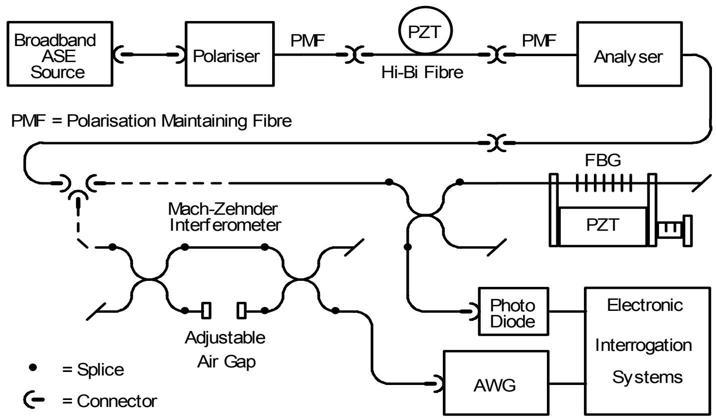

Fig. 1. Experimental set-up.

the provision of a low cost sensing solution. Alternatively, in the laboratory a fibre (or combined fibre and free-space) Mach-Zehnder interferometer is often used. Such devices employ low cost components however, precise adjustment of the optical path difference is very time consuming and the system is usually very susceptible to environmental perturbations that might affect the fibre in one arm, but not the other.
In this paper we demonstrate a solution which is of potentially low cost, permits simple adjustment of the optical path difference and has a much lower sensitivity to environmental perturbations than the fibre Mach-Zehnder interferometer. The

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idea is to exploit the ability to obtain interference between the fast and slow modes of a polarisation maintaining (PM) fibre. This has been used directly as a sensing mechanism [3], but has not to our knowledge been used as a means of interrogating other optical sensors.

2. EXPERIMENTAL SET-UP

The experimental set-up is shown in Fig. 1. A non-polarised erbium-doped fibre amplified spontaneous emission source provided 12dBm over a 33nm bandwidth centred on 1545nm. The light passed through a polariser, into a single eigenaxis of a length of PM fibre, through a connector (which could be rotated through 360^0) and into a second piece of PM fibre forming the processing interferometer. This connector was oriented to equally populate both eigenmodes of the second PM fibre. The second PM fibre was wound on a piezoelectric fibre stretcher connected to a function generator able to produce, using a serrodyne waveform, a 2π phase shift between the two modes of the fibre. The light then passed through a second rotating connector into a third piece of PM fibre, with eigenaxes oriented at 45 degrees to those of the second fibre. An analyser was then used to permit light in just one eigenmode of the third piece of PM fibre to propagate to a connector, and from there either to an FBG sensor or an interferometric sensor, depending on the system being studied. The FBG sensor consisted of a single Bragg grating mounted onto a second piezoelectric fibre stretcher so that dynamic strain signals could be applied; reflected light from the FBG sensor was directed through a coupler to a photodiode and relevant electronic interrogation system. The interferometric sensor consisted of a Mach-Zehnder interferometer with an air gap in one arm to permit adjustment of the optical path difference (OPD); the light output from the interferometer being directed to an arrayed waveguide grating (AWG) interrogation scheme [4, 5].

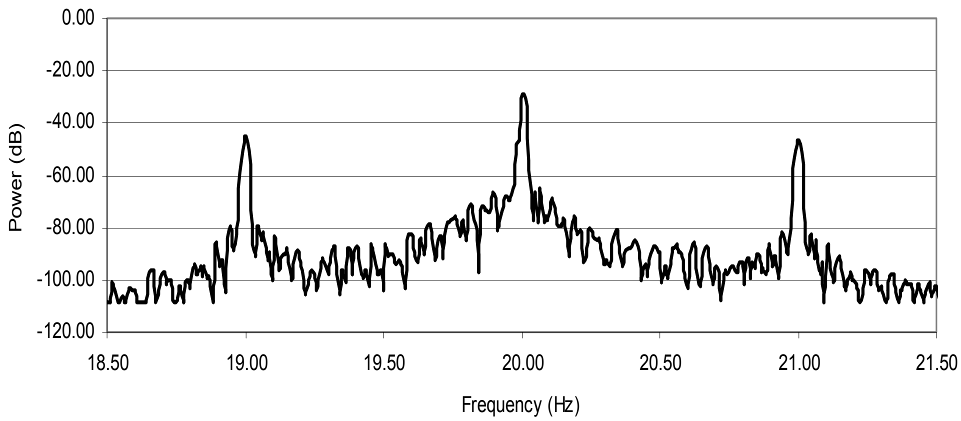

Fig. 2. Typical spectrum due to a FBG with applied sinusoidal strain modulation of 1με at 1Hz on a 20Hz carrier (7.63mHz bandwidth).

3. PM FIBRE INTERFEROMETER

With this configuration, the second piece of PM fibre effectively forms a Mach-Zehnder interferometer with the two optical paths corresponding to the two eigenmodes of the fibre with a differential delay determined by the birefringence, Δn and the length of the PM fibre, L. The free spectral range (FSR) of this interferometer is

$$FSR = \frac{\lambda^2}{\Delta n L} \tag{1}$$

where λ is the central wavelength of the light source and ΔnL is the optical path difference (OPD) of the interferometer. The differential nature of this type of interferometer means that both arms are subject to similar amounts of environmental perturbations reducing phase drifting of the interferometer output. A 21.56m length of PM fibre was selected to produce an FSR of 0.3nm and an associated OPD of 8mm; 20m of this fibre were wound on the piezoelectric stretcher used to generate a carrier for the signal processing schemes. We oriented the eigenmodes and demonstrated the operation of the PM fibre interferometer by increasing the amplitude of a 0.25Hz serrodyne waveform driving the stretcher and monitoring the fringe positions at the output of the PM fibre with an optical spectrum analyser. The strain required to produce a 2π phase shift between the eigenmodes with this set-up was approximately 6με.

4. FBG SENSING

The first demonstration using the PM fibre interferometer adopts a heterodyne approach using interferometric wavelength shift detection [2]. We modulated the phase of the PM interferometer at 20Hz and applied a low frequency strain amplitude of 1με at 1Hz to the FBG sensor. The FBG had a centre wavelength of 1558.3 nm and a -3dB linewidth of 0.13nm. The output of the photodiode was bandpass filtered (at the carrier frequency) and connected to a lock-in amplifier (LIA). A typical recovered signal seen at the output of the photodiode is shown in Fig. 2 demonstrating a noise limited resolution of around 100nε/√Hz. We used the serrodyne modulation frequency as the reference for the LIA and monitored the phase shift using an oscilloscope connected to the output of the LIA. The results are shown in Fig. 3 and show the recovered 1Hz strain signal applied to the FBG sensor.

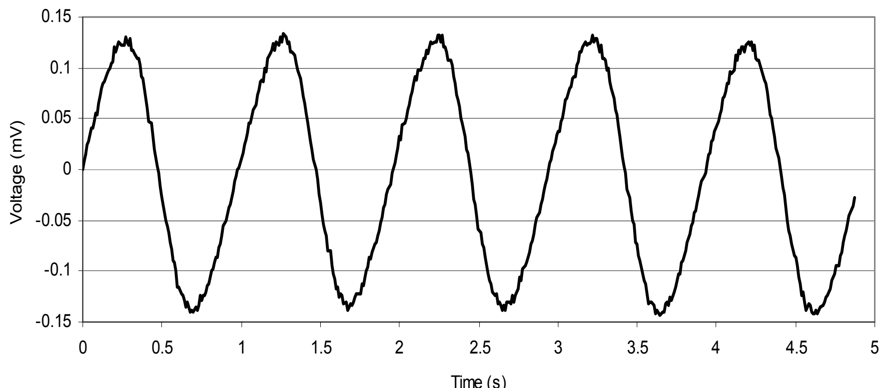

Fig. 3. Recovered 1με signal at 1Hz.

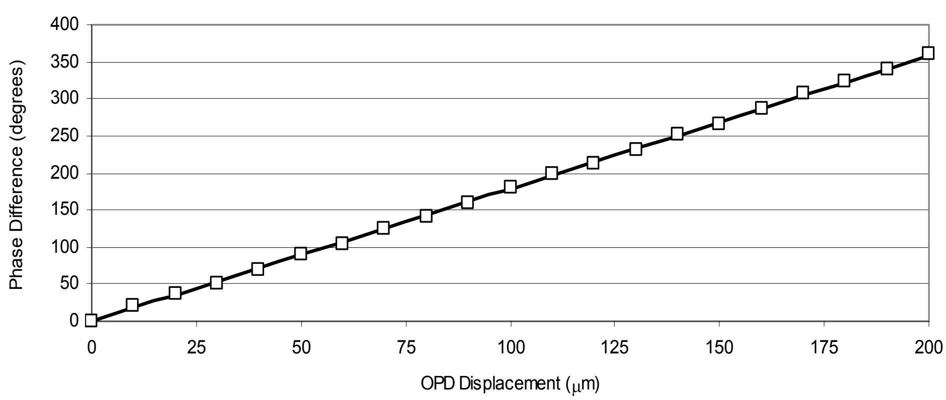

Fig. 4. Phase difference vs. Mach-Zehnder OPD. Experimental results (squares). Theoretical relationship indicated by the solid line.

5. INTERFEROMETRIC SENSING

In this demonstration we used the PM fibre interferometer to interrogate the Mach-Zehnder interferometric sensor, the two OPDs being closely matched in a coherence tuned system [6]. We again modulated the phase of the PM interferometer at 20Hz and used an AWG to implement a dual wavelength scheme [7] by using its outputs to synthesise two separate low coherent light sources illuminating the system [5]. We then monitored the phase differences corresponding to the two virtual sources using a LIA as we adjusted the OPD of the Mach-Zehnder interferometric sensor. The results are shown in Fig. 4. The unambiguous range in terms of a change in the Mach-Zehnder OPD is 200μm for the two selected synthesised light sources. The rms deviation from linearity is 1.1μm.

6. CONCLUSION

The experimental work reported here has demonstrated that an interferometer formed in PM fibre can be used at low cost to interrogate FBG and interferometric sensors. The main limitations of the demonstrated system are the long fibre length and low carrier frequency, resulting from the simple PZT driven translation stage used. The inclusion of a power amplifier driving a multi-element piezo electric stack should enable the bandwidth to be pushed up into the kHz regime whilst enabling higher strains to be used with concomitant reductions in the fibre length and sensitivity to environmental perturbations.

7. ACKNOWLEDGEMENT

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