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Interrogation of Fibre-Optic Interferometric Sensors Using An Acousto-Optic Tunable Filter

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Abstract

A new technique for the interrogation of interferometric-based fibre-optic sensors using an acousto-optic tunable filter (AOTF) is demonstrated. The scheme involves frequency shift keying (FSK) of the RF drive to the AOTF to track the shift of a single fringe peak from an interferometric sensor. Experimental results are presented for a Fizeau interferometer. The technique provides high accuracy, plus a large unambiguous tracking range, free from interruptions.

Fibre-optic interferometric sensors have been the subject of a large research effort[1-2]. Sensors of this type offer a high sensitivity for a wide range of physical measurands (such as displacement, strain, pressure, temperature, vibration, magnetic field, etc.), and can be operated either in a single sensor or in a multiplexed network. However, interrogation of interferometric sensors is a non-trivial task primarily because of the periodic nature of an interferometer response. This results in a variable scale factor, which is not acceptable in most sensor applications. To resolve this problem, numerous techniques have been developed[3-7]. These include the active homodyne method where active feedback is arranged to stabilize the interferometer at quadrature point[3], the passive homodyne approach where optical technique are used to generate two output signals 90° apart[4], the heterodyne technique where light in one of the arms of the interferometer is frequency shifted with respect to the other[5], and synthetic heterodyne or pseudo-heterodyne where the heterodyne signal is produced by phase-modulating the interferometer[6] or frequency-modulating the light source[7]. However, many of the above methods have limitations when it is desired to sense slowly varying (quasi-static) measurands (e.g. pressure and temperature), and all are difficult to implement in a stable manner. We have previously demonstrated a practical AOTF-based wavelength interrogation system for accurately tracking the fibre Bragg grating sensors[8-9]. We now report for the first time that out system is equally well suitable for the tracking of fringe shifts in interferometric sensors.

The principle of the system is shown schematically in Fig.1. Light from a broadband optical source is coupled via a fibre coupler into a Fizeau interferometer, resulting in a periodic modulation of the initial smooth spectrum (ie. interference fringes), the pitch of which characterizes the optical path difference (OPD) of the interferometer. The optical signal is then passed through the AOTF and to a detector. An AOTF facilitates fast tuning of its centre wavelength (typically 10 μs setting time) over a very wide wavelength range (usually greater than one octave). As the wavelength of the light transmitted by the AOTF is determined by the RF frequency drive to the AOTF, tracking the optical wavelength of a particular interference fringe can be accomplished by applying a FSK signal to the AOTF. This results in a square-wave amplitude-modulation of the transmitted light, where the peak-to-peak modulation is a function of the difference between the peak wavelength of the fringe and the centre wavelength of the AOTF, and its polarity depends on which direction the AOTF and the fringe are offset in wavelength. The square wave output from the optical receiver is then multiplied by the modulating signal, integrated and added to the modulating signal, thereby controlling the central AOTF wavelength to track the peak wavelength of the fringe. Once the central wavelength of the AOTF coincides with the peak wavelength of the fringe, the amplitude modulation of the light at the dither frequency will be zero. Because the mean RF frequency drive to the AOTF determines the central AOTF wavelength, the peak wavelength of the fringe can be monitored extremely precisely by measuring this frequency, which provides an indication of changes in the OPD and hence the measurand.

The system allows both scan and lock-in modes of interrogation. In the scan mode, the feedback loop is disabled. By driving the VCO with a linear ramp signal, the RF frequency can be scanned over the desired range. As a result, the AOTF will be tuned over a corresponding wavelength range so that the maximum detected power corresponding to the peak wavelength of the fringes can be determined to avoid any ambiguity on first switch on. In the lock-in mode, the VCO is driven with a low-frequency square wave so that an FSK signal is applied to AOTF and a particular fringe can be tracked once the feedback loop is enabled.

Fig.1 shows our experimental system. The broadband source was a 1300 nm single-mode, fibre-pigtailed ELED with ~10 μW output over 62 nm bandwidth (FWHM). The optical receiver was an InGaAs photodetector with a 500 MΩ transimpedance amplifier. The fibre-pigtailed AOTF had a wavelength tuning range of 1.2 μm-1.6 μm and a bandwidth (FWHM) of 1.5nm. The Fizeau cavity was formed between the end faces of a single-mode fibre and a reflective glass-block mounted on a piezotranslator, to simulate a displacement sensor. Also the piezotranslator was mounted on a micrometer positioner to allow a coarse tuning of displacement. The rear-surface of the glass-block was rough-ground and painted to avoid spurious reflections. The fibre output at the sensor was 5μW. The displacement of the sensor was accurately set by varying the driving voltage of piezotranslator (34 nm/V). The mean AOTF frequency was monitored using a TTL logic counter. The air cavity was 20μm for the initial experiment. Fig.2 shows the measured displacement response, with a scale factor of -5.84 kHz/nm. The insert shows the spectrum of optical signal. At a measurement period of 100ms set by the gating period of the frequency counter, the standard deviation for OPD measurement was 1.5×10^{-6}. The accuracy of the frequency measurement, and hence the displacement resolution is determined by the measurement period and the clock accuracy. The real-time response (see Fig.3) was also measured when the Fizeau cavity was subject to an rms displacement of 120nm at a frequency of 3 Hz using a measurement period of 20ms.

In summary, we have demonstrated an attractive technique for the interrogation of an interferometric fibre sensor using an acousto-optic tunable filter. The peak wavelength of the interference fringe can be tracked very precisely in real time and the system is suitable for slowly varying measurands. Initial experiment has been carried out for displacement monitoring. The advantages gained from using this technique are the ability to achieve high accuracy as well as large unambiguous measurement range, free from interruptions. The system developed is therefore likely to provide a practical means for the interrogation of interferometric fibre sensors.

Acknowledgements

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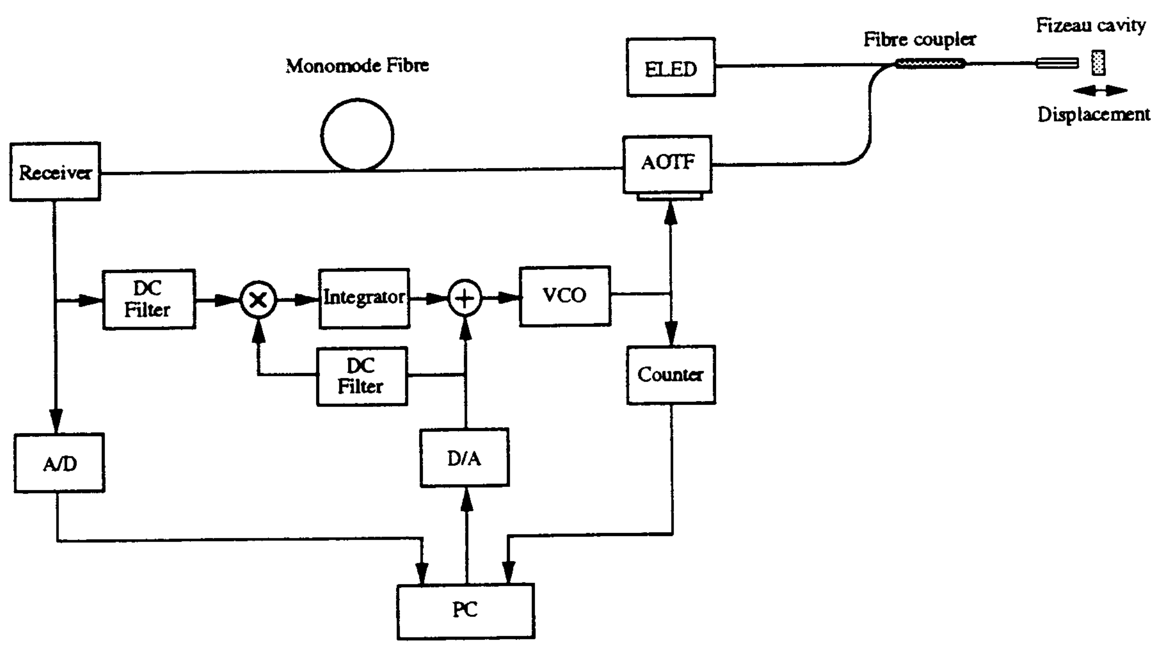
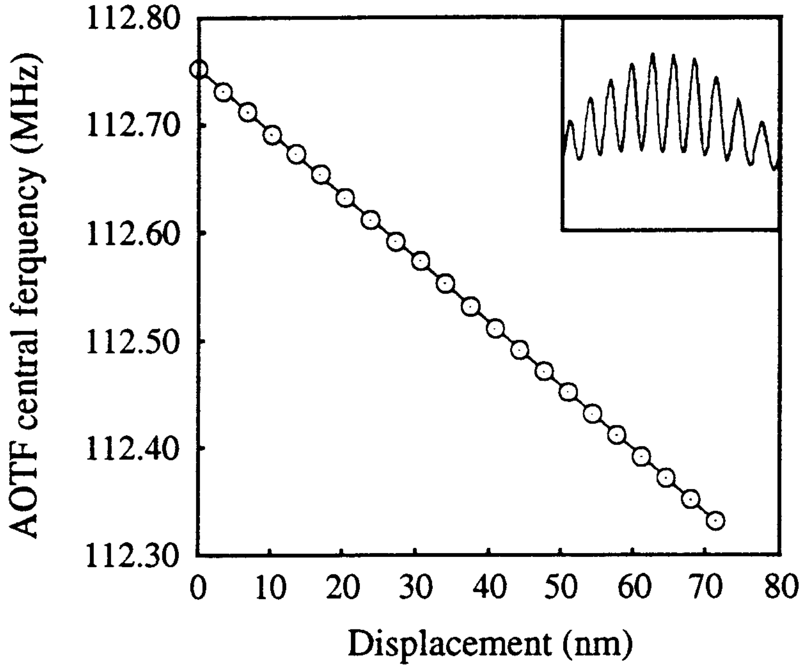
Figure captions

Fig.1 Schematic of an AOTF-based interrogation system for the interferometric fibre sensors. The system provides automatic tracking of measurand-induced fringe shift.

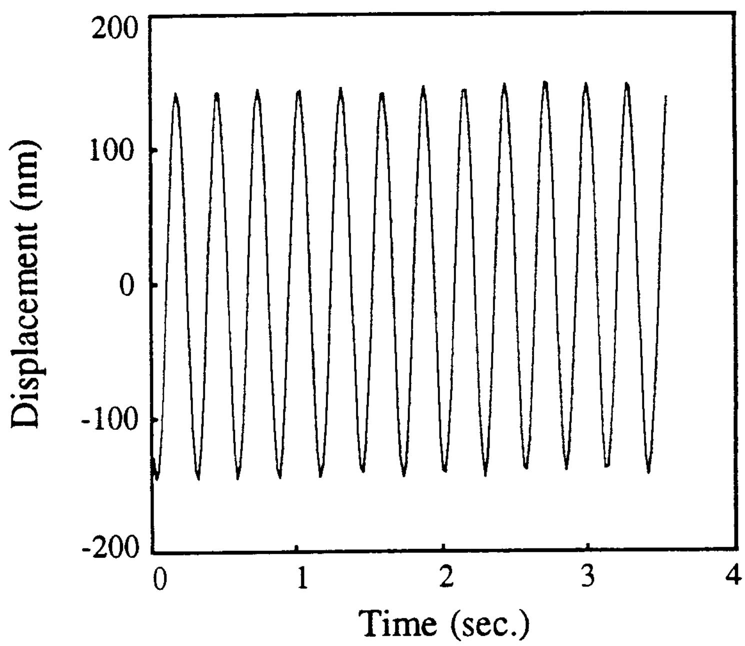
Fig.2 Tracking of Fizeau displacement sensor. A linear fit of the measured data gave a scale factor of -5.84 kHz/nm. The insert shows the spectrum of optical signal.

Fig.3 Real-time displacement monitoring when the Fizeau cavity was subject to an rms displacement of 120nm at a frequency of 3 Hz.





AOTF central ferquency (MHz)
112.80
112.70
112.60
112.50
112.40
112.30
0
10
20
30
40
50
60
70
80
Displacement (nm)



Displacement (nm)
200
100
0
-100
-200
0
1
2
3
4
Time (sec.)