Novel Dispersion Compensating Module based Interrogator for Fiber Bragg Grating Sensors

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Abstract We propose and demonstrate a novel interrogator for fiber Bragg grating (FBG) sensors using a dispersion compensating module. High speed potential of this scheme has also been investigated.

Introduction

Fiber Bragg gratings (FBGs) have proved themselves as the most appropriate sensors for measuring strain and temperature in smart structures, civil engineering or other harsh environments. The advantages of FBG sensor over conventional techniques include small size, light weight, immunity to electromagnetic interference, low cost and other inherent advantages of fiber optic sensors. Above all, FBG emerge as the most successful one due to its wavelength-encoded nature which make it insensitive to the intensity fluctuation due to losses in the fiber and connectors [1]. One of the key technologies for FBG sensor system is the interrogation of wavelength-shift. Various approaches have been developed such as scanning filters, tunable laser, interferometry, discriminator using the power ratios of optical filters, holographic grating based spectroscopic charge coupled device (CCD), long period gratings, chirped FBGs and so on [2]. High speed interrogation is one of the desirable features of FBG sensing system. Some schemes for high speed interrogation were proposed recently [3], [4]. In this paper, we proposed and demonstrated a novel high speed FBG sensor interrogation system using dispersion compensating module to convert wavelength to time measurement.

Experimental setup and operation principle

Figure 1 shows the experimental setup of the high speed FBG interrogation system. An erbium-doped fiber amplified spontaneous emission (ASE) source launches light into port 1 of a 3-port circulator and illuminates the FBG array via port 2 of the circulator. Some of the light whose wavelength falls in the reflection spectrum of the FBG array will be reflected back to the circulator. Light from port 3 of the circulator is launched to the electro-optic modulator (EOM) which is modulated by a pulse pattern generator (PPG) to generate one bit “1” follows by a serial of bit “0”. The pulsed signals from the FBG array is then feed to the dispersion compensating module. The spectral component within the pulses comprised the wavelength reflected by the FBG array and due to the large dispersion of the dispersion compensating fiber (DCF), different wavelength components take different time to propagate the DCF. The pulsed signal is detected by a 10 Gb/s photoreceiver and measured with a oscilloscope. By measuring the time shift, we obtain the wavelength shift information. The wavelength shift $\Delta \lambda$ is given as $\Delta \lambda = \Delta t/D$, (1) where $\Delta t$ is the time shift and $D$ is the total dispersion of the DCF. The basic principle is that instead of measuring the wavelength shift using a wavelength meter, it is converted to the time-difference which can be easily measured using a low-cost but high-speed oscilloscope.

The Broadband ASE source (Amonics, AEDFA-27-SHP) used in this experiment has + 27 dBm saturation output power and operating wavelength is from 1540 nm to 1565 nm. The EOM (JDSU, OC-192) is a 10 Gb/s LiNbO$_3$ modulator which is controlled by a pulse pattern generator (Anritsu, MP1763B). The dispersion compensating module (OFS, WBDK: 170-C) is a 3.525-km long wideband dispersion compensating fiber which has a total dispersion about -170 ps/nm at 1550 nm.

![Fig. 1: Experimental setup of the proposed high speed FBG interrogation system.](image)

Experimental results and discussion

To demonstrate the high speed FBG sensor interrogation system, we deploy 3 FBGs whose wavelengths are 1540.63 nm, 1549.98 nm and 1558.92 nm. All of the 3 FBGs have reflectivities higher than 90%. The data length of PPG is 64 bits and we set the first bit to be “1” and follows by 63 bits
of “0”. For 10 Gb/s PPG, the bit period is 0.1 ns, and this 64-bit sequence will then cover a period of 6.4 ns. Figure 2 shows the measured optical spectrum of the 3 FBGs and the corresponding measured waveform, the FBG at 1549.98 nm is under strain tuning. The gain peak of the EDFA source is around 1531 nm. We glued the FBG whose central wavelength is at 1549.98 nm to a translation stage, and strain can be applied on it by adjusting a screw. As shown in the figure, when strain applies to the FBG, its central wavelength will shift to longer wavelength and thus the corresponding pulse in time-domain will shift. The wavelength spacing for the 3 FBGs is about 10 nm, which means a 1.7-ns spacing in time-domain. If we take one of the FBGs as reference, we can then determine the wavelength shift of the other two FBGs.

![Optical spectrum and time-domain spectrum](image)

**Fig. 2:** (a) Measured optical spectrum and (b) time-domain spectrum of the 3 FBG sensing signals with the FBG at 1550 nm under strain tuning.

Figure 3 shows the time shift as a function of the wavelength shift. For the oscilloscope (Agilent, 86100A) used in our experiment, the highest timebase resolution is 2 ps/division and thus the wavelength shift resolution can be achieved is ~12 pm in our case. Although dispersion compensating modules with higher total dispersion are available, it would introduce higher loss and larger signal pulse broadening that make accurate peak measurement difficult to achieve. Curve fitting techniques could be employed to improve the accuracy of detecting the peak of the broadened waveform.

![Time shift vs wavelength shift](image)

**Fig. 3:** Time shift as a function of wavelength shift.

The proposed FBG sensing interrogator require no moving parts and can demodulate FBG at very high speed. Moreover, due to the rapid progress of optical communications, high speed devices such as modulators and photodetectors are becoming inexpensive and readily available. In our experiment, a 10 Gb/s modulator was used to generate 0.1 ns pulses with a repetition rate of ~156.25 MHz. This time period covers a wavelength range of about 37.65 nm. It should be noted that there is a trade-off between the interrogation speed and the measurable wavelength range. Furthermore, data processing time will also reduce the interrogation speed of the whole system. At this stage, we only have data averaging after receiving returned FBG signal. As shown in Figure 2, the measured waveform was obtained after average of 64 signals. By taking advantage of high speed data processing, we believe the proposed system is promising for high speed interrogation of FBG sensors.

**Conclusions**

In conclusion, a novel FBG sensing interrogation system has been proposed and demonstrated experimentally. The system has the potential for high speed demodulation of FBG wavelength shift.

**References**