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Year 2005

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This article was originally published as: Li, E, Xi, J & Chicharo, J, Multi-point fiber Bragg grating based vibration measurement system with high sensitivity and fast frequency response, The 18th Annual Meeting of the IEEE Lasers and Electro-Optics Society (LEOS 2005), 23-27 October 2005, pp. 804-805. Copyright IEEE 2005.

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Multi-point fiber Bragg grating based vibration measurement system with high sensitivity and fast frequency response

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Abstract: We have proposed and demonstrated a new fiber Bragg grating (FBG) based vibration measurement system which can demodulate vibration signals from wavelength-multiplexed FBG sensors with high sensitivity and fast frequency response.

Fiber Bragg grating (FBG) sensing has attracted considerable attention in both scientific research areas and engineering applications because of its distinguishing features including wavelength multiplexing ability, high sensitivity, long operating life and immunity from electro-magnetic interference, etc. FBG sensing has been widely used to measure various physical parameters including strain, temperature and pressure in different fields ranging from the so-called smart structures, structural health monitoring to aerospace industries. FBG sensing is based on the detection of the shifted Bragg wavelength of the light reflected by a fiber grating which is sensitive to the variations of strain and temperature. One of the important and challenging tasks in FBG sensing is to accurately determine the Bragg wavelength shift caused by the measurands. Tunable optical filters, such as Fabry-Perot (F-P) filters, are frequently used to detect the Bragg wavelength shifts. This technique has a number of advantages including high accuracy and multi-channel wavelength demodulation capability. However, limited by the highest scanning rate (a few hundred Hz) the current F-P filter can achieve, the wavelength demodulators based on F-P filters are usually used in static or quasi-static measurements. Another issue with F-P filter based FBG demodulators is that the wavelength resolution is limited to a few picometers. For many dynamic applications, such as vibration measurements, high resolution and fast frequency response are necessary. In this case, normal F-P based FBG sensing systems cannot be used.

In this study, we propose a new technique in order to overcome the above-mentioned issues of the F-P filter based FBG sensing systems and to meet the requirements imposed by the dynamic measurements. Instead of using continuous scanning method, we adopt a step-scanning scheme.

A schematic diagram of the system is shown in Fig.1. The structure of the system is similar to that of a normal FBG sensing system with a tunable F-P filter as its wavelength demodulation element. An ASE source is used as a broadband light source. The FBG sensors with different Bragg wavelengths are connected in series to a single fiber cable which is linked to the second port of an optical circulator. The broadband light signal from the ASE source is reflected by the FBG sensors at the designated wavelengths, and redirected to the third port of the circulator. A tunable F-P filter is connected to the third port of the circulator. The tunable F-P filter is controlled by a DC voltage from a D/A

converter on a data acquisition card plugged in a PC computer. The output of the F-P filter is connected to a photo-detector of a power meter where the optical signal is converted to electrical signal and amplified, then fed to an A/D converter of the data acquisition card.

A new scanning scheme is proposed in the current FBG sensing system. At the beginning of a measurement, the computer controls the tunable filter to continuously scan a wavelength range which covers all the connected FBG sensors and records the output signal from the power meter. This process is just like that of normal FBG sensing systems using tunable F-P filters. The difference is that the recorded spectral data are used to determine the operation point for each FBG sensor and the calibration constant for that sensor. Corresponding to each FBG sensor, there is a peak in the recorded spectral response. In order to measure the FBG wavelength shifts caused by dynamic strain imposed by the FBG sensor, the computer calculates the peak locations and sets the F-P filter to the rising edge (or falling edge) of the first peak, and then starts the A/D converter to record the data. After the predetermined data points have been reached, the F-P filter is set to the rising edge (or falling edge) of the second. The process is repeated until all the FBG sensors are demodulated. It should be noted that for each FBG sensor, the wavelength demodulation is achieved by using an edge-filtering process. Therefore, the frequency response of the wavelength demodulation process is completely determined by the frequency response of the photo-detector, which could be in a range of MHz or even higher. Another advantage of the edge-filtering technique is that a high wavelength resolution and sensitivity can be achieved. As the data are recorded when the F-P filter continuously scans over the whole wavelength range in a real time and in-situ manner, the calibration process already takes the following effects into account: (1) losses introduced by the optical components in the fiber link; and (2) possible slow wavelength variations caused by other factors such as temperature changes.

We constructed an FBG sensing system according to Fig.1. In the demonstration system, we used two FBG sensors which were attached to two PZT actuators to introduce vibrations. Limited by the highest frequency response of the PZT actuators used in the experiments, vibrations with 3 kHz have been detected by using the developed sensing system. A wavelength resolution better than 0.1 pm could be easily achieved. The proposed sensing scheme can also be applied to the F-P based FBG sensing systems by simply modifying the control software.

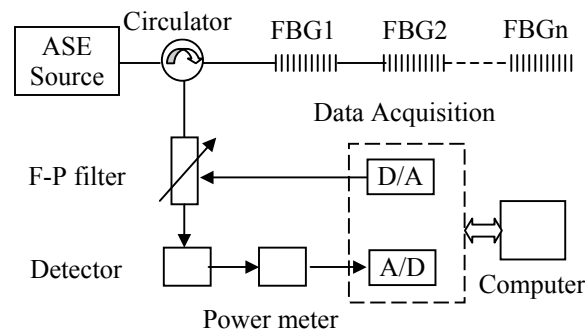


Fig. 1. Schematics diagram of the proposed FBG sensing system