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HIGH SPEED WAVELENGTH DETERMINATION SYSTEM FOR WAVELENGTH-ENCODE SENSORS

SPECIFICATION

1. Field of the Invention

The present invention relates generally to the field of fiber optic sensors and more particularly to determining wavelength returns from fiber optic sensors.

2. Description of the Related Art

The basic prior art concept for addressing multiple Bragg gratings consists of a broadband source such as a light-emitting diode (LED), edge-emitting LED (ELED), or other superluminescent device illuminating a series of gratings along a fiber (a 'string' of gratings). When illuminated, each Bragg grating reflects a narrowband component of light at the Bragg wavelength, given by the expression:

$$\lambda_B = 2n\Lambda \qquad (1)$$

where Λ is the grating pitch and n is the effective index of the core. Perturbation of the grating, by temperature or strain, for example, results in a shift in the Bragg wavelength, which can be detected in the reflected spectrum. This shift can then be compared with the unperturbed Bragg wavelength to determine the extent of the perturbation.

One of the benefits of an FBG sensor lies in the fact that information is encoded into wavelength. This has a number of distinct advantages over other direct intensity based sensing schemes. Most importantly, wavelength is an absolute parameter. As a result, wavelength measurements are not affected by total light levels, losses in the connecting fibers and couplers, or source power.

Thus, fiber optic sensors based on the use of fiber Bragg grating (FBG) devices are useful in a variety of applications. They are particularly useful as embedded sensors for smart structures where the sensors can be used for real time evaluation of load, strain, temperature, vibration, and other variables. Since many gratings can be written into a length of fiber and addressed using multiplexing techniques, FBG sensors can provide quasi-distributed sensing capabilities.

Previously, a conventional optical spectrometer was used to determine the return wavelengths. Use of such a device is usually time-consuming and practical only in a laboratory environment. A key to capitalizing on the benefits of Bragg sensing in field applications lies in the fast and reliable detection of grating reflections. In light of the foregoing, there is a need for a system and method to provide fast, high resolution determination of the wavelength returns from an array of gratings.

Summary of the Invention

Accordingly, the present invention is directed to a digitally controlled wavelength tunable filter and zero-crossing detection algorithm to provide fast, high resolution of the wavelength returns from an array of gratings. The system is portable, inexpensive, and therefore suitable for field applications.

Additional features and advantages of the invention will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the invention will be realized and attained by the system and method particularly pointed out in the written description and claims hereof, as well as the appended drawings.

To achieve these and other advantages, a system according to this invention includes a digital counter, a converter which receives a digital input from the digital counter and produces an analog output to drive a tunable optical filter, a string of gratings, having a source of illumination at one end, coupled to an input of the filter to direct spectral returns from the gratings into the filter, a processor for processing light passing through the tunable optical filter; and a latch, responsive to the processor and coupled to the digital counter, for capturing the digital signal of the digital counter.

In another aspect, a method according to this invention includes the steps of digitally counting through a range of digital values, converting the digital values to analog values, driving a tunable optical filter with the analog values, illuminating a fiber optic string of gratings, coupling the string to the tunable optical filter to direct spectral returns from the gratings into the filter, processing the light passing through the tunable optical filter, and selectively capturing the digital values based on the processing;

Both the foregoing general description and the following detailed description are exemplary and explanatory and do not restrict the invention as claimed. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, explain the principles of the invention.

Brief Description of the Drawings

These and other objectives, features and advantages of the invention, as well as the invention itself, will become better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein like reference numerals designate identical or corresponding parts throughout the several views and wherein:

Fig. 1 is a schematic block diagram of an apparatus for addressing an FBG array according to the present invention;

Fig. 2(a) shows the optical return signal from the Bragg gratings of Fig. 1;

Fig. 2(b) shows the spectrum of the scanning optical filter of Fig. 1;

Fig. 2(c) shows the electrical signal present at the output of the photodetector of Fig. 1;

Fig. 2(d) shows the electrical signal present at the output of the derivative unit of Fig. 1; and

Fig. 3 is a diagram of a derivative circuit.

Description of the Preferred Embodiment

Reference will now be made in detail to the present preferred embodiment of the invention, an example of which is illustrated in the accompanying drawings. Where possible, like numerals are used to refer to like or similar components.

The exemplary embodiment of the wavelength determination system of the present invention is shown in Fig. 1. As embodied herein and referring to Fig. 1, the wavelength determination system includes an edge-emitting light-emitting diode (ELED) 10, which transmits light through single mode optical fiber 15, through optical coupler 25, and into single mode optical fiber 16. A number of fiber Bragg gratings (FBGs) 20 are written into the optical fiber 16, in a manner well known in the art. These FBGs 20 will reflect specific optical wavelengths back through optical coupler 25 and into a tunable optical filter 30.

The digital output from a digital, up/down counter 35 is converted to an analog voltage by a digital-to-analog (D/A) converter 40 and summed in a summing circuit 41 with a direct current (dc) offset voltage from an offset circuit 45 (to be discussed) to provide a signal to tune the tunable optical filter 30.

A photodetector 50 converts the optical output of tunable optical filter 30 into an electrical signal. A derivative unit 55 takes the derivative of this electrical signal and feeds it into zero-crossing detection circuitry 60. When zero-crossing detection circuitry 60 detects a zero-crossing, it sends an electrical signal to a latch 65 which captures the current value of up/down counter 35. A computer (PC) 70 stores and processes the latched value. A more detailed description of the invention will be given below in connection with its operation.

In Fig. 1, depicting the preferred embodiment of the invention, ELED 10 transmits light into the optical fiber 16 which contains a plurality of fiber Bragg gratings 20. The FBGs 20 reflect certain wavelengths of light according to equation (1).

Fig. 2(a) depicts a typical set of return wavelengths for three FBGs 20 located along optical fiber 16. Optical coupler 25 directs the FBG return wavelengths into tunable passband optical filter 30, preferably a fiber Fabry-Perot (FP) filter. As is well known in the art, the passband of FP filters may be altered by electrically controlling the piezoelectric material creating the mirror spacing of the filter. The free spectral range of optical filter 30 must correspond to the range of possible reflected wavelengths from the FBGs. For example, using an array of 12 FBGs spaced by 3 nanometers (nm), the FP filter should have a free spectral range of around 45 nm.

In the present invention, a ramp waveform 42 controls the passband of optical filter 30. To generate ramp waveform 42, the 16-bit up/down counter 35 continuously counts from its lowest digital value to its highest, and back down. This 16-bit digital signal is fed into the D/A converter 40 which converts the signal to analog form, resulting in the ramp waveform 42. Ramp waveform 42 controls the passband of the optical filter 30 so that the optical filter 30 scans through the range of wavelengths reflected by the FBGs 20, an appropriate offset 45 from offset circuit 45 is added to ramp waveform 42 to properly bias it. Fig. 2(b) shows a typical passband of an FP filter, which scans through a wavelength spectrum.

As the passband of optical filter 30 sweeps through the spectral range, the FBG spectral returns are accordingly passed through optical filter 30 to photodetector 50. Photodetector 50 converts the FBG spectral returns into electrical signals, shown in Fig. 2(c). The peaks in this signal correspond to the reflected wavelengths from the FBGs. Therefore, it is necessary to precisely isolate the center of the peaks. The profile width of optical filter 30, however, limits the resolution of the photodetector signal. To improve the resolution, derivative unit 55 takes the derivative of the photodetector signal, resulting in the signal shown in Fig. 2(d). The derivative of the photodetector signal produces a zero-crossing t_{B1}, t_{B2}, and t_{B3} at each of the central wavelengths of the peaks in the photodetector signal.

The derivative of the signal may be performed in an analog circuit, a microprocessor or through the digital circuit shown in Fig. 3. In Fig. 3, the circuit 55' corresponds to derivative unit 55 in Fig. 1. The photodetector signal of Fig. 2(c) is passed to a fast analog to digital (A/D) converter 56 (such as the 16-bit Burr-Brown ADS7811) and then to a digital stack (RAM) 57, which serves to delay the measured value by a predetermined number of clock cycles N. A digital subtraction unit 58 then digitally subtracts the delayed photodetector signal from the direct signal to form an approximation of the signals shown in Fig. 2(d).

Zero-crossing detection circuitry 60 receives the output signal from derivative unit 55. When the voltage of the signal fed to zero-crossing detection circuitry 60 equals zero, the circuitry 60 activates latch 65. Latch 65 captures the current value of up/down counter 35, which corresponds to the wavelength optical filter 30 was tuned to when zero-crossing detection circuitry 60 detected a zero-crossing. This value can then be compared in the exemplary computer 70, to the previously stored value associated with the unperturbed zero-crossing return wavelength. To ensure that zero-crossing detection circuitry 60 does not trigger latch 65 during spurious zero-crossings between actual FBG returns, the circuitry preferably contains a threshold detector. The threshold detector detects when the input signal rises above a predetermined level, shown by the dotted line 62 of Fig. 2(d), and signals to zero-crossing detection circuitry 60 that the next zero-crossing corresponds to a true FBG return.

In sum, perturbations of the gratings alter the Bragg resonance conditions and change the wavelength of the reflected components. This results in shifts in the counter values at which zero-crossings occur that can then be translated into wavelength shifts representing the degree of perturbation. Using this approach, the central wavelength of several FBG sensors can be determined during each scan ramp cycle of the tunable FP filter. Scanning the filter at rates of several hundred hertz to potentially several kHz allows rapid updating of the FBG wavelengths. The use of the exemplary 16 bit up-down counter 35 for generation of the ramp signal provides a least significant bit resolution of less than 1 picometer (pm) for a filter with a free spectral range of less than 60 nanometers (nm). This wavelength resolution corresponds to a strain resolution of less than 1 μstrain at an operational wavelength of about 1.3 micrometers or microns (μm).

It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the spirit or scope of the invention. For example, a variety of filters could be substituted for the Fabry-Perot filter, such as cascaded Mach Zehnders, acousto-optically tuned filters, polarization based filters, and in-fiber grating based filters. Also, a different broadband source such as an LED could be substituted for the ELED. It is intended that the present invention cover the modifications and variations of this invention.

ABSTRACT

A system and method for determining the return wavelength of fiber Bragg grating sensors using opto-electronic processing of the returned signal with a digitally controlled scanning filter element.