Dynamic demodulation of spectral shifts in fiber-Bragg-grating sensors

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A photorefractive-crystal-based two-wave-mixing interferometer allows structural-health monitoring of civil, aerospace, and mechanical structures.

Fiber-optic sensors are receiving significant attention in structural-health monitoring (SHM) of large-scale structures. They allow for on-board diagnostic monitoring of a structure’s damage state and its dynamic response to changing environmental conditions. In particular, these sensors offer attractive, on-demand assessment capabilities for monitoring structural changes in safety-critical complexes such as bridges and aircraft.

Various sensing systems are used for SHM, including accelerometers, strain gauges, displacement transducers, and dynamic weight-in-motion and fiber-optic sensors. The latter, based on fiber-Bragg gratings (FBGs), are of particular interest for monitoring dynamic mechanical and thermal strains because of the comparative advantages they provide. FBG sensors are inexpensive, readily available, lightweight, immune to electromagnetic-noise sources, and can be used for multipoint sensing in a sensor-array network.

A common approach for interrogating FBG sensors involves transmission of a broad-band light source through the sensor and monitoring the spectrum of the reflected light from the FBG. The center wavelength, λ₀, of the reflected light depends on the period and effective index of refraction in the sensor’s gauge section. Any perturbation in these quantities due to mechanical or thermal strain leads to a shift in λ₀, which is monitored with a spectral demodulator.

A variety of spectral demodulators are available, including spectrometers, scanning tunable filters, and unbalanced path-length interferometers. We have developed a two-wave-mixing (TWM) interferometer that enables demodulation of small dynamic wavelength shifts (<4pm) in an indium phosphor photorefractive crystal (PRC). Our device offers some competitive advantages compared to other demodulators. It is self-adaptive and allows monitoring of dynamic (>300kHz) wavelength shifts in the presence of large quasistatic background signals. Spectral demodulation of dynamic FBG signals is achieved without the need for intermittent wavelength tuning, scanning, or complicated feedback electronics, as common to other techniques. The interferometer also allows for wavelength-division multiplexing of several FBG-sensor outputs with a single demodulator.

A schematic diagram of our TWM demodulator is shown in Figure 1. It shows a single FBG sensor epoxy-bonded on a thin aluminum plate. The sensor is illuminated by a broadband amplified spontaneous emission (ASE) laser in the C band (the ‘erbium window’ between 1530 and 1565nm). The reflected

Figure 1. Schematic of our two-wave-mixing wavelength-demodulation system. FBG: Fiber-Bragg grating. PRC: Photorefractive crystal. ASE: Amplified spontaneous emission. TWM: Two-wave mixing. λ/2: Half-wave plate.

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light from the FBG is delivered to an erbium-doped fiber amplifier (EDFA). The EDFA output is split into signal and pump beams by a 1×2 coupler with a 95/5% power ratio, and the beams are directed along unbalanced optical-path lengths into the PRC, where the signal and pump beams interfere, forming a dynamic volume hologram through optical interference and the photorefractive effect. The dynamic hologram diffracts the signal and pump beams such that, in the direction of the transmitted signal beam, a local oscillator (diffracted pump beam) that has the same spatial phase structure as the transmitted signal beam is produced. Both beams interfere, leading to an intensity change proportional to the spectral shift of the FBG sensor. The timescale of the photorefractive effect is short (∼1ms), thus allowing for selective demodulation of dynamic spectral shifts above 1kHz. Figure 2 shows a typical demodulated spectral response of the FBG sensor to an impact load on the aluminum plate. The measured data consist of a dispersive guided Lamb wave mode excited in the plate. The upper frequency limit is approximately 200kHz. This demodulation system has also been applied for multiplexed spectral demodulation of FBG-sensor-array responses in impact-source localization.

In summary, we have developed a PRC-based TWM interferometer for dynamic spectral demodulation of FBG-sensor responses. Our future plan is to demonstrate the suitability of the FBG-sensor system for SHM of bridges and aircraft structures.

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