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Fiber Sensor Utilizes Both Raman and Brillouin Scattering

Fiber sensors are replacing traditional transducers in myriad monitoring and measuring applications, a result of the fiber sensor's superior reliability, longevity, and flexibility to function in multiple sensing applications. In one example, fiber sensors have measured both strain and temperature when the fiber is illuminated with laser light, and the signal reflected back by Brillouin scattering is quantified. Such simultaneous measurement could be useful, for example. in real-time monitoring of the strain and temperature in a critical engine part.

Brillouin scattering can be understood as a purely classical effect, in which the laser light is reflected from a spontaneous sound wave propagating in the fiber. Because the sound wave is moving, the light reflected from it is Doppler shifted to a different frequency. The velocity of the sound wave can be inferred from the magnitude of the frequency shift of the reflected light. Because the velocity of the sound wave depends on both the temperature of the fiber and the strain it is subjected to, the measured frequency shift contains information about both parameters.

An immediate problem is that one cannot distinguish between the frequency shift due to temperature, and the frequency shift due to strain, in the Brillouin-scattered light. To finesse this problem, investigators have developed a Brillouin time-domain reflectometry technique, in which pulses of light reflected from different portions of the fiber are separated by their return time to the detector. By making independent measurements of the Brillouin frequency shift and intensity, the investigators are able to calculate both the strain and temperature along the fiber. Unfortunately, this technique is limited by the accuracy of the intensity measurement.

Recently, scientists at the University of Southampton in Southampton, U.K., have demonstrated a technique of simultaneously measuring the Brillouin- and Raman-scattered light from a fiber, and from those measurements inferring both the temperature and strain, with greater accuracy than has been achieved with the Brillouin scattering alone. The intensity of Raman-scattered light contains information about the temperature alone, and once the temperature is known, the strain can by computed from the frequency shift of the Brillouin signal.

Raman scattering is a quantum-mechanical effect, in which a photon is scattered from a molecular vibration. In the most-common case (i.e., first Stokes), the photon loses an amount of energy necessary to boost the molecule to an excited level. The intensity of Raman scattering depends on the thermal population of the molecular energy levels, and hence the intensity of Raman-scattered light is a function of temperature. Strain, on the other hand, has virtually no effect on the energy levels or their populations, so the Raman signal is not affected by strain.

The Southampton scientists used a narrow-linewidth laser at 1533.2 nm, together with a pair of erbium-doped fiber amplifiers and an acousto-optical modulator, as the probe source in their demonstration (Figure 1). A circulator (Circulator 2 in Figure 1) separated the return signal from the fiber sensor and sent it to the detectors. The sensor itself comprised four different sections of fiber and was 1.3 km in length, separated from the source/detector by 22 km of spooled fiber (demonstrating that the detector could be located a significant distance from the source/detector). The first section of the sensor (400 m) was in an oven at an elevated temperature of 60 °C. The second section (600 m) was at room temperature (20 °C), subject to no strain, and provided a reference signal. The third section (130 m) was suspended from a system of pulleys and loaded with weights to induce a known strain. The final section (200 m) served as a second reference section.

The acousto-optic modulator chopped the probe light into 100-ns pulses, which enabled a spatial resolution of approximately 10 m in the fiber. The Raman-scattered light, shifted by approximately 100 nm, showed a clear intensity enhancement from the section of the fiber inside the oven (Figure 2). The Brillouin-scattered light showed a frequency shift both from the section of the fiber in the oven, and from the section of fiber stretched over the pulleys (Figure 3.) From the data in Figure 2, the Southampton scientists calculated that the section of fiber in the oven was heated to 60 °C, consistent with the directly measured temperature in the oven. Knowing the temperature profile, they were then able to calculate the strain in the section of fiber stretched over the pulleys. As indicated by the irregular profile is Figure 3, the strain was not uniformly distributed due to friction in the pulley system. The resolution of the temperature measurement was ~6 °C, and the resolution of the strain measurement was ~150 με.

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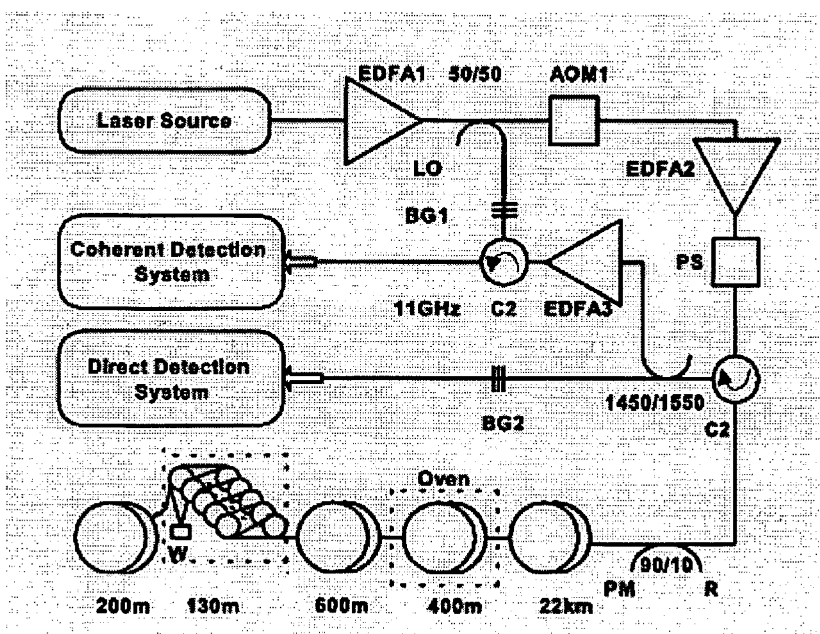

Figure 1. The scientists directly detected the intensity of the Raman -scattered light, whose wavelength was shifted by ~100 nm from the laser wavelength. They used a coherent-detection scheme to measure the frequency shift of the Brillouin-scattered light.

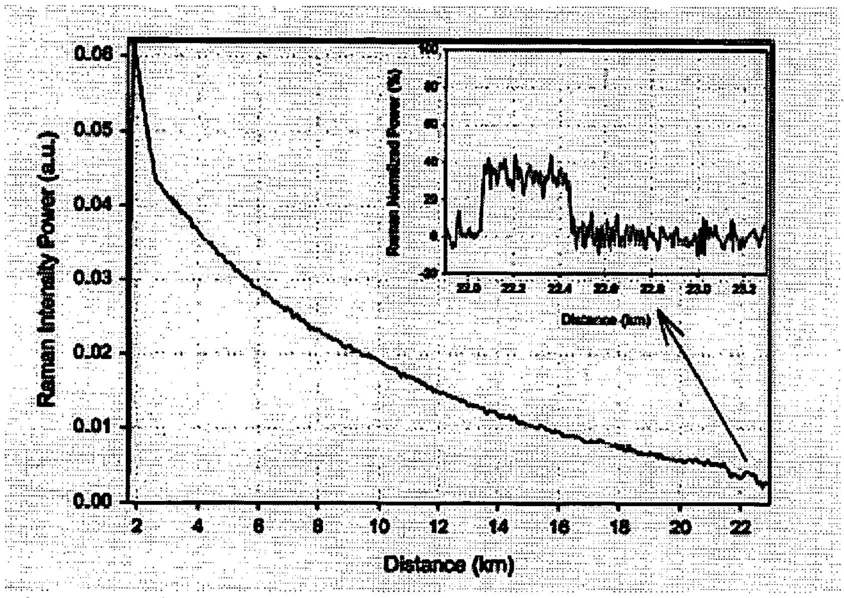

Figure 2. The Raman-scattered showed a clear intensity enhancement from the section of fiber in the oven. Inset: The signal from the 600 m of fiber in the oven, and the following 400 m of reference fiber, normalized to the Raman signal when the oven was at room temperature.

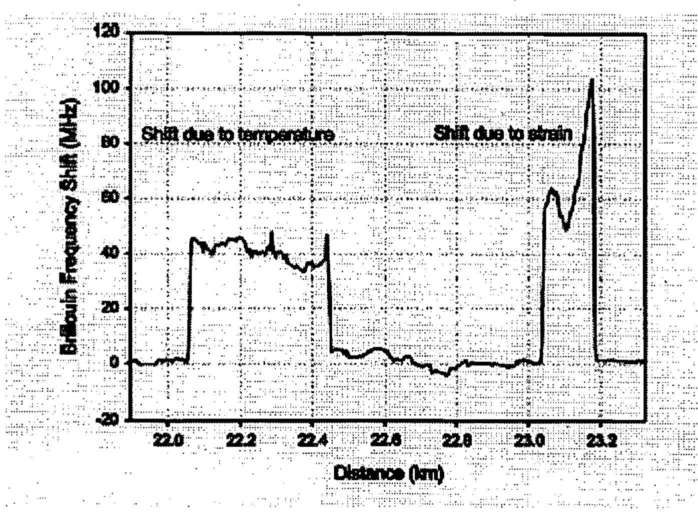

Figure 3. The frequency shift of the Brillouin-scattered light showed a different frequency shift from the section of the fiber in the oven, and from the section of fiber stretched over the pulleys. The strain was uneven as a result of friction in the pulley system.