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Characterization of a differential fiber Bragg grating sensor for oil-water boundary detection

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Abstract

We investigate the operating characteristics of an oil-water boundary detector utilizing differential interrogation of fiber Bragg grating sensors. The system resolution is shown to be stable with respect to the choice of strain actuator and long-term temperature changes and changes in the initial strain on the fiber string. Fluid flow, particularly turbulent flow, is found to reduce system resolution significantly for the current system design. Improvements in the system design are required to minimize the effects of fluid flow and to accurately detect the presence of oil-water emulsions. © 2005 ISA—The Instrumentation, Systems, and Automation Society.

Keywords: Fiber sensors; Bragg grating; Differential; Strain; Fluid flow

1. Introduction

Fiber Bragg gratings (FBG's) are popular components for sensor systems measuring temperature, pressure [1–4], and dielectric constant [5,6]. FBG's provide a wavelength-encoded signal that is highly sensitive to environmental conditions. The signal is sufficiently narrow banded that highly accurate measurement with multiplexed sensor arrays is possible [4]. Wavelength resolutions in the subpicometer range are possible, resulting in microstrain resolutions [3,7]. Many methods have been proposed to demultiplex the wavelength encoded signal and extract the required information. The spatial separation method [6,8] is of particular interest to our group, as the receiver can be simply constructed from readily available components, is easily miniaturized, and lends itself well to differential detection methods.

A common aspect of the sensor systems proposed to date is that the receiver calculates the absolute value of the variable under study. Differential measurement offers the potential advantage of increasing resolution by reducing the impact of system noise. To date, differential measurement has been used primarily to improve the accuracy of point strain measurements [9,10]. In many cases, differential measurements provide sufficient information about the process under investigation. One such case is the detection of oil-water boundaries in oil production facilities, which cause a change in specific density (translated into pressure) or refractive index that may be detected by an optical sensor. In our previous work, we demonstrated that the spatial demultiplexing method permits highly sensitive differential detection without calculating the absolute reflected wavelengths of the individual sensors [11,12].

In this paper, we further characterize our differential detection system. We first evaluate the sensitivity of the system as a function of actuator design and material composition. We then explore

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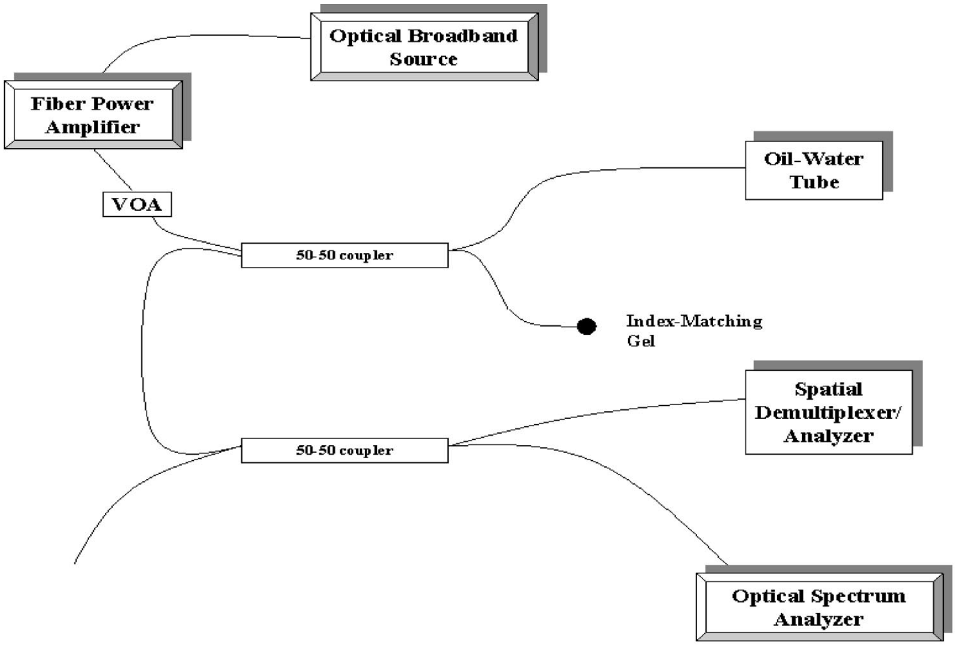

Fig. 1. System for probing fiber Bragg grating sensors. Index matching gel was placed on the unconnected end of each grating to minimize unwanted reflections.

the behavior of the system under perturbation from environmental factors such as fluid motion and long-term variations in temperature and initial strain conditions. We also report on preliminary attempts to reduce the system sensitivity to fluid motion.

2. Experimental methods

2.1. Stimulus and processor configuration

Two fiber-Bragg grating (FBG) sensors, obtained from Thorlabs, Inc., were probed using the system depicted in Fig. 1. The sensors had center wavelengths of 1555.57 and 1557.32 nm and a bandwidth of 0.2 nm. The sensors were spaced 40.6 cm apart. A broadband source (Photonetics WIN-SOURCE 1300/1500nm) and fiber amplifier (Newport FPA-15) provided adjustable optical input power to the system around 1550 nm. A variable optical attenuator (VOA) (Ocean Optics) could be inserted between the amplifier output and the first coupler to adjust the input power. Light reflected from the FBG sensors returned through the first coupler into a second coupler. The second coupler divided the sensor signal between an optical spectrum analyzer (OSA) (Anritsu MS9001B1) and the spatial demultiplexing-based analyzer (SDA) described below. In this way, parallel recording of the sensor signal by the OSA and SDA was possible. Index-matching gel applied to the unused coupler ports minimized stray reflections. The center wavelength of each sensor's signal was measured using available functions on the OSA and was accurate to 10 pm.

The spatial demultiplexing-based analyzer used for our experiments utilized a blazed diffraction grating, mirrors, and an infrared-sensitive camera. Details of the SDA are described elsewhere [12]. The SDA records wavelength as lateral position along the input array of the charge-coupled device (CCD) camera (Sensors Unlimited, SU128-1.7LT, 128×128). The exact spatial location of the optical signal on the camera was determined by processing the camera signal on a personal computer. Image acquisition hardware and software converted the image into standard data files for processing. A measure of camera noise was obtained by blocking the sensor signals with an opaque screen and capturing the resultant image. The noise data was then subtracted from the signal data, resulting in a final data set. A minimum of four data sets were taken for each measurement conducted and subsequently averaged. The central