Optical Fiber-Based Pressure Sensor for Power Plant Applications

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Service Provided: Gammacell® Irradiator

Sponsors: Electric Power Research Institute

Introduction

This project investigated the application of optical fiber Bragg sensors for gauge and differential pressure sensing in nuclear power plant applications. An emphasis was placed on developing a sensor package with a form factor similar to existing nuclear power industry pressure transmitters. A commercial optical fiber interrogator located remotely from the measurement location detects changes in the reflected wavelength of the light within the optical fiber, and a connected computer converts the optical wavelength shift into the corresponding change in pressure. Remote optical interrogation eliminates the need for sensor read-out electronics in the measurement environment. This extends the life of the sensor, which is often limited by the effects of temperature and radiation on the measurement electronics.

Development

The sensor was designed and built at the Pennsylvania State University Applied Research Laboratory. The sensor uses a commercially available, optical fiber Bragg grating sensor that measures strain and temperature in a single package. Fluid pressure couples to a pair of pressure chambers inside the pressure sensor; the optical fiber Bragg grating sensor measures strain induced by the pressure in the chambers. The interrogator detects the resulting strain as a change in the wavelength of the light reflected by the Bragg grating inside the fiber. A separate Bragg grating within the same fiber provides a temperature measurement that is used to compensate for temperature-induced strain. Figure 1 shows the sensor installed in the Pennsylvania State University Steam Plant, where it measured differential pressure across a boiler feedwater valve.

Testing

The pressure sensor underwent a series of tests to characterize the response of the pressure sensor to environmental conditions, seismic events, and long-term radiation exposure. This radiation test simulated the exposure associated with loss of coolant accident (LOCA) conditions in a reactor building. The metric used in this test was the performance of the sensor after exposure to gamma-ray radiation. Testing was performed at the PSU Radiation Science and Engineering Center using the Gammacell 200. The sensor was exposed to a total dose of 15 MRads.

The complete sensor housing would not fit into the test cell, so the sensor was stripped down to just the main measurement components: the two pressure vessels, the optical fiber Bragg grating transducer, and the inlet pressure ports. Figure 2 shows a photograph of the sensor mounted in the Gammacell exposure chamber

FIGURE 1: The optical fiber-based pressure sensor (left) was installed in the Penn State Steam plant as part of long-term performance testing, and measured differential pressure across a boiler feedwater valve (right).

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FIGURE 2: The core components of the optical fiber pressure sensor were mounted in the Gammacell 200 for irradiation testing.

(the chamber is lowered into the unit to expose it to the radiation). The optical fiber interrogator and a laptop computer were located outside the Gammacell and used to monitor and record the output of the optical fiber sensor.

The two pressure ports were tied together to one pressurized N_2 line to provide the pressure input to the sensor; hence, the differential pressure was 0 throughout the testing while the absolute pressure was varied across the sensor range. During the test period the absolute pressure was increased from 0 to 1000 psi in 500 psi increments. The output of the interrogator was collected continuously during the test. Interrogator data was collected to analyze two sensor parameters: strain wavelength and the returned optical signal power.

The first parameter relates directly to sensor accuracy; the second parameter relates to sensor sensitivity. The strain wavelength is used to calculate the differential pressure, which should remain constant (at zero psi) throughout the test at each absolute pressure. The second parameter relates to the sensitivity of the detection system. There is a concern that exposure to radiation can change the optical characteristics of the Bragg grating at the heart of the sensor, an effect known as fiber darkening. If the Bragg grating deteriorates due to exposure to environmental factors such as radiation, it decreases the strength of the return signal. If the grating were to experience enough degradation, the interrogator would no longer be able to detect changes in the wavelength and hence not be able to detect changes in pressure.

Following exposure to 15 MRad of gamma-ray radiation, there was no detectable degradation in sensor performance. A slight change in optical signal strength was measured for both the strain and temperature sensors, but it did not affect interrogator performance. This effect is expected as a result of fiber darkening. The performance of the interrogator was unaffected because the interrogator signal-to-noise ratio (SNR) is much higher than the measured change in optical signal level due to the radiation exposure. The interrogator optical power dropped approximately 1.5 dBm as a result of the radiation exposure; however, the nominal SNR of the Micron Optics interrogator is greater than 30 dBm, so the system could still measure the output of the sensor even after the -1.5 dBm reduction in the signal. Consequently, the interrogator would still be able to measure the output of the sensor after approximately 20 times as much radiation exposure.

Conclusions

The Pennsylvania State University Applied Research Laboratory has successfully designed, constructed and tested a pressure sensor for nuclear power plant application capable of measuring gage and differential pressure. The sensor uses commercially available optical fiber Bragg grating sensors and a commercially available optical fiber interrogator system. The use of the optical fiber sensor and interrogator allows remote monitoring of pressure and eliminates the need to locate measurement electronics within the radiation environment, which can significantly increase the operational lifetime of the sensor. The availability of the PSU Radiation Science and Engineering Center's Gammacell 200 was instrumental in measuring the long-term radiation effects on sensor performance and showed that the sensor performance would not degrade over its expected useful life.

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References

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