Versatile Acoustic and Optical Sensing Platforms for Passive Structural System Monitoring

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ABSTRACT: The objective of the proposed research is to develop an acoustic based distributed sensing system capable of monitoring phenomena such as strain, temperature, pressure and corrosion to better evaluate the aging and degradation of relevant structural components including concrete that serves as support and nuclear containment; cable insulation; and metal pressure boundaries, in nuclear facilities. In the proposed three-year program, Principle Investigators from the Center of Photonics Technology (CPT) at Virginia Tech, will collaborate with Prysmian Group, an industry leader in optical fiber and cable manufacturing with over 70% share of the optical fiber cable market for nuclear power plants, and Oak Ridge National Laboratory (ORNL), to develop a distributed acoustic fiber Bragg grating sensing (AFBGs) technology. This first-of-its-kind sensing system will be developed with unprecedented resolution, versatility, reliability, and economic viability, and can be radiation hardened via the use of acoustic fiber waveguides (AFWs) designed and constructed from radiation tolerant fused silica and sapphire fibers. The performance of the AFBGs and AFWs will be qualified via comprehensive theoretical modeling, experimental validation, and radiation exposure testing. A prototype AFBG based sensing system will be benchmarked against commercially available fiber optic sensing techniques in a representative target environment in a laboratory setting.

Continuous health monitoring of these components has become of paramount importance to proactively address potential failures that result in the shutdown of operation and/or health and environmental risks. Subsequently, there has been an intense interest in fiber optic sensing technologies because of their relative tolerance to radiation exposure and elevated temperatures. Nonetheless, challenges remain prevalent with respect to reliability and cost. The proposed approach of creating Bragg gratings on acoustic fiber waveguides for sensing external perturbations harkens back to the development of the first optical fiber Bragg gratings (OFBGs). Similar to an OFBG, the AFBG is formed by a large number of serial, periodic property modulations along the fiber. Interrogation is performed with an acoustic pulse whose spatial length in the fiber covers only a small portion of the continuous AFBG and the center frequency of the acoustic signal reflected from an AFBG segment can be related to perturbations of the AFBG at that location. In addition, the arrival time of the reflected acoustic signal can be related to the location of the AFBG segment where the acoustic pulse is reflected. Therefore, distributed temperature measurement can be realized by real-time monitoring of the center frequencies of the acoustic pulses reflected from different locations of the fiber. Furthermore, because of the low bandwidth requirement on the interrogation electronics, the cost of the entire system can be significantly lower than most of the commercially available sensor types for the same spatial coverage (<5 cm).

The proposed research performed in this project will fill the gap between low cost electronic sensors and high performance fiber optic sensors, and create a new arena for the development of the next generation of sensing technologies. Successful demonstration of the technology will provide a first-of-a-kind, low-cost, fully-distributed, multi-parameter sensing platform that can operate reliably in a nuclear and high temperature environment, and will offer a powerful means for the deployment of distributed fiber sensor arrays for 3D network monitoring solutions.