U.S. Department of Energy

Remotely bonded optical fiber sensors and actuators for ultrasonic structural health monitoring of reactor components in harsh environments

PI: Kara Peters, North Carolina State University

Collaborators: Ge Yang, North Carolina State University; co-PI: Cliff J Lissenden, Penn State University

Program: Measuring, Monitoring, and Controls

ABSTRACT:

Fiber optic (FO) sensors have been widely successful for the measurement of environmental loading conditions within commercial nuclear power plants. The US Department of Energy Office of Nuclear Energy's Advanced Sensors and Instrumentation (ASI) program has funded several critical advances to enable FO sensors for nuclear applications, including single crystal sapphire-based FO sensors, high-temperature fiber Bragg grating sensor fabrication techniques, FO sensor fused smart alloy components for reactors, and resilient fiber packaging for fibers and feedthrough requirements. These systems have focused on the measurement of distributed temperature, pressure, and strain in nuclear environments and components. However, the critical information that is missing from the current FO data collection systems is quantitative data on the structural conditions of specific components that is available from ultrasonic waves. Currently, the primary challenge to incorporating the generation and collection of ultrasonic waves into existing FO sensor systems for reactor environments is transporting the ultrasonic waves in the reactor structure efficiently to the optical fiber.

To tackle this pressing technical issue, the North Carolina State - Penn State team will design, implement and evaluate remotely bonded FO sensors for the measurement of acoustic emissions and actively generated ultrasonic waves in the harsh environments within advanced nuclear reactors. Ultrasound inspection is the leading technology for remote monitoring of structures due to its flexibility to assess both elastic properties (through wave speeds) and discontinuities like cracks (through wave scattering). A significant step in this design process will be the direct contact mode coupler between the acoustic waveguide and component, as well as coupling from the acoustic waveguide to the optical fiber.

The research program will involve four major research tasks: (1) selection, synthesis, and characterization of candidate materials for adhesion of FO-based systems to structural components in reactor environments; (2) design of the structure-acoustic waveguide mode coupler to maximize the extraction of ultrasonic mode energy from the component to the detection system; (3) evaluation tests of the system to measure acoustic emission and active guided ultrasonic waves in tensile fatigue and pipe specimens; and (4) demonstration of the performance of the ultrasonic guided wave detection system in a high temperature and radiation environment at the PULSTAR facility at NCSU.

The measurement system developed in this project will extend the capabilities of other FO sensing systems developed/being developed through DOE sponsored research to measure temperature, pressure, strain, etc. for the nuclear power industry. Our FO structural health monitoring (SHM) sensors are envisioned to detect acoustic emissions from progressing damage and active ultrasound signals indicative of existing damage in reactor components. This capability will help the US Department of Energy Office of Nuclear Energy achieve its objective to advance U.S. nuclear power to meet the nation's energy needs by developing innovative nuclear instrumentation for advanced and current-generation reactors.