Monitoring Ceramic Fuel Fracture via Fiber Optic Acoustic Emission Sensors

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ABSTRACT: In the proposed three-year program, the Center for Photonics Technology (CPT) at Virginia Tech will collaborate with Sentek Instrument (Sentek), Prysmian Group (Prysmian), and Idaho National Laboratory (INL) to develop and demonstrate a distributed acoustic emission (AE) sensing system for in-situ monitoring of ceramic fuel fracture and structural components in nuclear power plants. The proposed monitoring system leverages a proven and breakthrough fiber optic sensing technology that enables the harmonic-free interrogation of thousands of grating-based distributed interferometers along an optical fiber to enable ultra-sensitive ($< 0.2\ n\varepsilon$) vibration measurements that can be configured with high spatial resolution ($\leq 2m$) and sampling rates ($\geq 400\ kHz$). The one-of-its kind technology enables femto-second laser inscription of the sensors in radiation tolerant optical fiber. The commercially available *picoDAS* system will be modified to enable the detection of acoustic phenomena at higher frequencies (> 200 kHz) and the sensing fiber will be coated with an "enhanced" polyimide coating for operation at temperatures in excess of 400°C. The relatively small diameter optical fiber (d ~250 µm) will be wrapped around the DRIFT (Dry in-pile fracture test) stainless steel insert assembly to obtain at least 20 sensor measurements with an approximate spatial resolution of 2.5 mm along the plane parallel to the centerline of the UO_2 pellet stack.

Fracture is inextricably linked to thermo-mechanical response of the ceramic nuclear fuel in a reactor and is driven by multiple phenomena. Fuel performance is dictated by this fracturing under normal operating conditions because it affects heat transfer through the fuel and can induce stresses in the cladding in the vicinity of the fuel cracks. It is also of interest for understanding fuel behavior during accident conditions because, in the event of cladding rupture, the dispersal of fuel fragments in the coolant is affected by their size. As such, the ability to accurately characterize the fracture of ceramic nuclear fuel is of considerable interest as part of a larger effort to improve the fidelity of fuel performance models. To meet this need, the team at INL recently developed the Dry In-pile Fracture Test (DRIFT) that employs a unique heat sink to perform a series of separate-effects experiments in the Transient Reactor Test (TREAT) facility. The results of these experiments will provide useable data on the process of fracture propagation in nuclear fuel under realistic service conditions, but there is a lack of instrumentation to monitor the acoustic emissions that accompany material fracture. In prior and current tests at TREAT, localization requires at least two transducers, one located above and one below the capsule. This configuration only provides an axial estimate (which has many uncertainties due to thermal gradients, acoustic interfaces/pathways, and potential EMI). Adding two relatively large transducers also has effects on both the temperature and radiation fields within the test, takes up valuable space, and adds leads which require more feedthroughs. The proposed fiber solution requires one feedthrough, is immune to EMI, allows for 3-D mapping of the signal, and is effectively radiation transparent.

The successful demonstration of the acoustic emission sensing system via integration with the DRIFT insert assembly in the TREAT reactor at INL will not only provide for in-situ characterization of the ceramic fuel fracturing phenomena, but also set the stage for the next generation of health and condition monitoring systems for critical nuclear power plants and advanced reactors.