Dual Mode High Temperature MEMS Ultrasonic Sensor for Structural Health Monitoring of Liquid Metal Reactor

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ABSTRACT:

The objective of this proposal is to develop a high temperature, multi-functional Micro-Electro-Mechanical-Systems (MEMS) sensor to provide *in situ* ultrasonic structural health monitoring (SHM) of piping systems in liquid metal-cooled fast reactors (LMFR). The proposed sensor will enable continuous SHM and detection of material degradation in LMFR piping components, with broader application to other high temperature advanced reactor platforms. The novel sensor is made from radiation-resistant high temperature materials, which will offer a longer operational lifetime in high-temperature and radiative environments, and better sensitivity/selectivity to incipient material degradation. SHM will be achieved by the dual functionality of the same MEMS sensor, which combines both continuous passive acoustic emission sensing and active guided wave ultrasonics. Since the MEMS sensor will be used for active and passive sensing, this effort will also minimize the number of physical sensor units needed for SHM at a nuclear facility. The sensor array will be coupled with a dry-contact mechanism without modification of pressure boundaries, which complies with regulatory qualification requirements. Furthermore, the manufacturing flexibility of MEMS will be leveraged to detect multiple wave modes (longitudinal and torsional) simultaneously. The proposed research will enable *real-time* SHM, which will minimize maintenance costs by reducing the probability of forced shutdowns related to failure of critical reactor components.

The capabilities of this sensor are unique – offering dual functionality, multi-mode selectivity, and mass manufacturing at low cost. The sensor will be designed to function at ~650°C, to be compatible with the typical operating temperatures ranges of LMFRs. For this purpose, the high temperature MEMS sensors will be fabricated with radiation-resistant aluminum nitride (AlN) as the sensing element, supported by a 4H-silicon carbide (SiC) substrate. 4H-SiC has a high bond energy due to a wide band gap, which makes it more stable at elevated temperature. Given the high temperature and expected long service life of nuclear components (>5 years), damage modes are anticipated to be a combination of creep and fatigue. The structural material defect size detection threshold and sensor resiliency under prolonged high temperatures will be investigated at UIC. To test the threshold detection size, small-scale mechanical tests will be performed to induce microdefect formation for detection with the MEMS sensors. Service testing using the auxiliary sodium test article at the Mechanisms Engineering Test Loop (METL) facility is planned, to qualify sensor operation in molten salt cooled reactor environments.

This project involves a multi-disciplinary team from academia, Argonne National Lab, and industry. The participation of MISTRAS Group, one of the leading companies in the field of nondestructive evaluation of structures, will increase the potential of transforming the sensor into practice through commercialization. As a designated Asian American and Native American Pacific Islander-Serving Institution and Hispanic-Serving Institution, the UIC team will recruit a diverse set of students to take part in this research, to prepare the future U.S. workforce for employment in the nuclear energy sector.