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Subwavelength Ultrasonic Imaging for Rapid Qualification of Additively Manufactured Nuclear Structures and Components

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ABSTRACT:

The objective of this proposal is to develop a transformational capability for rapid nondestructive quality assessment of nuclear additively manufactured (AM) structures and parts through advanced ultrasonic imaging with subwavelength resolution. Additive manufacturing offers efficient solutions for replacing obsolete and aging nuclear reactor parts and reduces costs for new construction of advanced reactors such as small modular reactors. Yet, AM structures contain processing-induced defects such as keyhole and lack of fusion pores which could result in an accelerated creep and corrosion of AM metallic components in the high temperature and neutron radiation environment of a nuclear reactor. Hence, the qualification of every AM component is required for deployment in a nuclear reactor environment. Currently, there is no accepted nondestructive method for the qualification of AM components for nuclear applications.

Ultrasonic imaging provides a rapid nondestructive assessment of internal microstructures in metallic structures, which, unlike radiographic techniques, is scalable to complex geometries and arbitrary sizes. However, the resolution of conventional ultrasonic systems is diffraction-limited by the incident wavelength (λ). To enhance image resolution and detect smaller defects, the ultrasonic frequency can be increased (yielding a smaller λ). However, an increase in the frequency may significantly decrease the efficiency of acoustic transmission and penetration of ultrasonic waves into materials, which presents undesirable tradeoffs in the scanning of the internal structure. In this proposal, we will exploit the negative refraction phenomena observed in periodic structures (phononic crystals/metamaterials) for subwavelength focusing of acoustic waves and aim to break the diffraction limits of ultrasonic imaging for air-coupled (0.5-1 MHz) and water-coupled (10-50 MHz) configurations. Hence, we will achieve far-field resolution down to 20 μm per mm thickness of the AM sample, which is not possible within the typical frequencies (up to 50 MHz) of conventional ultrasonics. We will test the enhanced ultrasonic imaging system by post-manufacturing quality assessment of AM parts with different sizes and complexities, such as plates of different thicknesses, internal passageways, and spacer grids. Uniquely designed calibration samples will be additively manufactured at U-M and ANL. Because of the uncertainties in the detection of microscopic defects, the positions of inclusions obtained by ultrasonic imaging will be further compared with X-ray tomography at U-M, thermography at ANL, and destructive evaluation using scanning electron microscopy at UIC.

This project involves a multi-disciplinary team from academia, a national lab, and industry. The participation of WEC, one of the world's leading producers of large components for nuclear power plants, will increase the ability to transform the rapid and high-resolution nondestructive evaluation approach into practice for quality assurance of additive manufactured nuclear components. The deliverables of the proposed project include (i) quarterly, annual, and final reports, (ii) conference presentations and journal publications, intellectual property disclosures, (iii) AM calibration samples for nondestructive evaluation, and (iv) the prototype of the high-resolution ultrasonic imaging system. If successful, this project will have a transformational impact on the nuclear manufacturing industry.