Fiber Sensor Fused Additive Manufacturing for Smart Component Fabrication for Nuclear Energy

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ABSTRACT:

The objective of this program is to establish the foundation for converging disciplines of fiber optic sensors and additive manufacturing (AM) for smart part fabrication for nuclear energy applications. Through innovation in computational design methods, study of AM procedure, and innovation in high-temperature fiber optic sensor development, this proposal will explore embedding fiber optic sensor in laser AM-processed metals for smart component manufacturing for nuclear power systems.

Through extensive computer simulations of the AM process, this NEET program seeks to develop new design and fabrication approach to embed fiber sensors to perform effective measurements and at the same time, maintain mechanical and thermal performance of nuclear components. Through experimental study, this NEET program seeks to develop new optical fibers and optimize femtosecond laser manufacturing process to produce sensors that are amendable to embedment by both directed energy deposition (DED) and laser powder bed fusion (LPBF) AM techniques. Through close collaboration with our national lab partners and industry collaborators, this NEET program also seeks to expand functionalities of the embedded fiber sensors to monitor both static parameters and dynamic parameters with high spatial resolution. This will enable condition-based monitoring of key components and systems of nuclear power systems.

The proposed research will address several gaps in scientific understanding associated with embedding an optical fiber by laser DED and LPBF techniques: 1) Relationship between AM process parameters (e.g. laser power and scan speed) with local thermal stress and melt pool geometry due to laser scanning of powders on the coated optical fiber; 2) relationship between laser scanning path with residual stress; 3) effect of local and part-scale temperature and residual stress on structural integrity of the embedded optical fiber; 4) effect of large difference in process parameter ranges between DED and LPBF have on fiber embedment effectiveness.

Key deliverables for this program include: 1) new type of optical fibers with high TEC suitable for fiber embedment, 2) robust computational model and optimization algorithm for optimizing AM process design and predicting thermal and mechanical performance of sensor-fused smart components, and 3) sensor-fused smart components that can perform high spatial resolution measurements of T, strain, vibration, and pressures in radiation environments.

<u>Potential Impacts:</u> The proposed research is relevant to NEET-1.1 with a focus on advanced modular factories, field fabrication and installation techniques. This project has the potential to transform current manufacturing practice of nuclear power systems such as small modular reactors and how they are monitored. Through integrated modeling and experimentation, our research team will develop an integrated additive manufacturing and fiber embedding technology that fuses reactor modular manufacturing and sensor installation into a single manufacturing step with feasible pathways to code/regulatory acceptance. The nexus of radiation-harden fiber sensors and AM could drastically simplify installation of monitoring instruments, reduce overall operational costs through sensor-enabled condition-based maintenance, and significantly improve safety margins and the economic viability of nuclear energy. Collaboration with the leading nuclear company will ensure that this project will have immediate impact and high relevance to the nuclear industry and that the developed technology will be rapidly transferred and adopted by the team partners to fabricate smart nuclear components.