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Turbulent MHD flow modeling in annular linear induction pumps with validation experiments

PI: Steven Shannon, NC State

Collaborators: Jacob Eapen, NC State

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ABSTRACT:

This project will advance the underlying technology of electromagnetic pumps and accelerate their readiness for future liquid metal reactor systems. While large induction EM pumps (LEMPs) offer the benefit of absence of moving elements, operability at high temperature, larger flow rates, system efficiencies exceeding those of conduction pumps, and simplification of the flow circuit, they also experience increased resistive heating from time varying current, and induced currents in the liquid metal. The complex field coupling generates deleterious end effects and hydrodynamic turbulence that is generated by the magnetic field heterogeneity; both which adversely affect the optimization of the pump performance. We aim to advance modern computational fluid mechanics (CFD) analyses to optimize LEMPs; the CFD analyses will be validated using a novel low temperature liquid metal test loop that is safe, scalable, low cost and equipped with a host of diagnostic tools. A tremendous amount of background work has been carried out on EMP and LEMP systems, and areas of improvement in fundamental understanding and modelling capability have been identified by research groups and science directorates, including the 2016 DOE-NEUP call for proposals. Specifically, the need for more complete multi-physics model of EMP systems, improved MHD solvers, and experimental validation of new more complete models is sited. NASA is evaluating liquid metal cooled fission reactors using NaK-78 for in-space systems and has tested small scale systems with flow rates up to Q = 5.7 L/s and pressures of p = 90 kPa. Main circulation pumps for sodium cooled reactors will have to approach larger flow rates on the order of 3,500 L/s. The annular linear induction pump (ALIP) configuration is the most promising EM pump configuration for these flow rates, demonstrating up to 1,000 L/s in heated sodium loops.

This proposed scope of work will advance ALIP design efforts for liquid metal reactors through three well defined and coupled thrust areas: 1.) Conduct scoping and trial CFD simulations on three experimental model systems to identify the effect of hydrodynamic and EM field coupling with NEK-5000, a high-order spectral element computer code with both (albeit decoupled) MHD and turbulence capabilities. The primary aim of Task 1 is to configure and experimentally validate Nek5000 while simulating complex time and space varying EM/hydrodynamic interactions, 2.) Leveraging the learning from the controlled trial conditions of Task 1, we will conduct high-fidelity large eddy simulations (LES) on model annular linear induction pump (ALIP) configurations to understand the effect of hydrodynamic turbulence and optimize the pump performance and efficiency, and 3.) Construct an experimental flow loop facility and diagnostic tools to benchmark to refine and validate the predictions of CFD analyses. This task involves fabrication of three model test configurations to support task 1 that provide a.) both simple validation tests of known HD and MHD phenomena and b.) a simplified EM structure that will advance simulation techniques in previously identified regimes that require improved understanding and simulation performance. This task also involves fabrication of a modular ALIP pump that, combined with the added accessibility provided by a non-volatile liquid metal surrogate, allows for a plurality of pump geometries and novel diagnostics for experimental validation of the simulation of ALIP systems.