A Computational Tool Compatible with NEAMS Code Packages for Optimizing the Shape of Nuclear Reactor Components and of Whole Core Performance

PI: Yousry Y. Azmy, NC State University

Collaborators: Sebastian Schunert, Idaho National Laboratory

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ABSTRACT:

We propose to design and implement a shape optimization tool that functions with NEAMS codes, and that nuclear scientists and engineers can employ to optimize the shape of individual components and the whole core under the applicable single- or multi-physics model comprising the employed code(s). The shape-optimization tool will enable varying the geometric shape itself as well as its dimensions to yield, potentially, new component designs that are not limited by the designer's intuition and previous experience. In cases where the optimal-shape object is an individual component, we will provide the capability for additional verification that the whole-core performance using the optimized component performs better, under the prescribed optimization criteria, than current designs. Our shape-optimization tool will couple to NEAMS codes via a flexible input-composer interface and will enable the user to constrain the shape's evolution to ensure the component's manufacturability. Finally, we will demonstrate our shape-optimization tool with single- and multi-physics NEAMS codes.

This objective is motivated by the recent advances in manufacturing technology that, combined with rising interest in novel reactor concepts, are creating new opportunities for innovation in the design of individual components that affect the performance of the full reactor system. In particular, Additive Manufacturing (AM) enables mass production of highly precise, intricate and complex component shapes that are not feasible with traditional manufacturing techniques.

To accomplish this goal we will develop and implement in MOOSE: (1) discrete shape optimization capability based on a state-space search that uses Artificial Intelligence strategies to find the optimal state/shape; (2) smooth shape optimization tool that employs PETSc's toolkit for advanced optimization (TAO) to optimize node-displacement of the components' model sidesets; (3) hierarchical core optimization workflow that recognizes the repeating patterns typical in a nuclear reactor and performs the optimization one level at a time with increasing length scale. Each of these tools will be equipped with user-specified constraints to avoid optimal shapes that are not manufacturable. The developed shape optimization tool will be verified and demonstrated on a heat-pipe micro-reactor and a molten salt reactor for which MOOSE models are already available in the virtual test bed (VTB). The optimization process will account for tightly coupled physics that govern the behavior of these reactors, and will exercise several NEAMS codes, e.g. Griffin, SAM, BISON, and Sockeye, in a coupled multiphysics fashion.

The impact of the delivered shape optimization tool will materialize in the optimal design, from the outset, of advanced reactors currently contemplated to regain the US's leadership in nuclear energy R&D. Novel reactor concepts, e.g. Molten Salt Reactors, and sizes/capacities, e.g. micro-reactors, provide a unique opportunity to optimize performance from the early stages of development, before the investment in components' production lines, validation experiments, and licensing regimes make future improvements in performance prohibitively expensive and force sub-optimal performance on the affected reactor concept in perpetuity. This benefit will be realized by the delivered shape optimization tool regardless of the applicable manufacturing process whether traditional or AM, thereby broadening the impact of this project on current and future reactor concepts and technologies.