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IMPROVED QUASI-STATIC METHODS FOR TIME-DEPENDENT NEUTRON DIFFUSION AND IMPLEMENTATION IN RATTLESNAKE

Abstract: Transient reactor simulations are a chronically formidable challenge due to the computational rigor of evaluating the neutron transport equation, as well as its coupling with other physical phenomena. The goal of this thesis research is to mitigate the computational expense of these simulations by investigating and developing the improved quasi-static method (IQS). IQS is a rigorous space/time multiscale approach whereby the neutron flux is represented by a time-dependent amplitude and a time-space-energy dependent shape. The objective of the IQS factorization is to evaluate amplitude and shape on different time scales in order to reduce computational burden associated with solving the multi-dimensional flux equations, while maintaining solution accuracy. IQS factorization leads to a nonlinear system of equations that requires iteration of shape and amplitude. Furthermore, reactor simulations often require coupling to additional multiphysics components for temperature feedback. These additional physics may evolve on different time scales and the applicability of IQS in multiphysic simulations needs to be evaluated from this perspective as well.

The objectives of this research is to establish IQS performance with various iteration techniques, validate time step convergence of IQS, and apply IQS to multiphysics simulation. IQS iteration techniques involve fixed-point (Picard) iteration with various convergence criteria and Newton iteration, namely preconditioned Jacobian-free Newton Krylov (PJFNK) method. Nonlinear convergence of each of these techniques is investigated. Validation of IQS with analysis of time step convergence is vital for implementation of time adaptive methods and error prediction. The time derivative of the shape function is discretized through fourth order using implicit-Euler, Crank-Nicolson, backward difference formulae (BDF), and singly-diagonally-implicit Runge-Kutta (SDIRK) methods. IQS application to multiphysics simulations involves its implementation into the Rattlesnake/MOOSE framework. These simulations allow insight to the performance of IQS for full transient reactor simulations.

The results of the iteration convergence analysis show that the most rigorous and comprehensive iteration technique is fixed-point iteration with consistency in the IQS uniqueness specification as the convergence criteria. This iteration technique revealed the need for analytical treatment of the precursor equation for proper convergence. For time step convergence analysis, IQS was applied to a one-dimensional prototype example, as well as the TWIGL and LRA benchmark. The prototype results show that IQS has proper error convergence through fourth order discretization schemes. The TWIGL and LRA benchmark results show that IQS has proper convergence for implicit Euler, second-order BDF, and Crank-Nicolson schemes, validating IQS for more complex problems. For multiphysics simulation, IQS was applied to the LRA benchmark and a full core TREAT model. The results show that integration of temperature into the quasi-static process made considerable improvement to IQS performance. These results and conclusions helped gain insight into the behavior of IQS and furthered its development in complete transient reactor models.

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Zachary Prince grew up in Honolulu, Hawaii and the Seattle, Washington area. He earned his B.S. in Mechanical Engineering from University of Arizona in 2015, studying under Dr. Barry Ganapol. He immediately began his M.S research at Idaho National Laboratory with the direction of Dr. Jean Ragusa. A few months later, he came Texas A&M to study Nuclear Engineering. Zach originally was awarded the College of Engineering Endowed Doctoral Fellowship, then in 2016 was awarded the NEUP Fellowship to pursue a PhD. He plans to continue development of computational methods for deterministic transport in his PhD and beyond.