Nodal Kinetics Upgrades

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Improvements to the NESTLE Kinetics package within RELAP5-3D.

In 1996, a Krylov-based linear solver, BiCGSTAB, was added to RELAP5-3D to solve the transient coarse mesh finite difference (CMFD) system used in the nodal kinetics solver. Previously, the CMFD solution was obtained using a Line Successive Over-Relaxation (LSOR) method, which required many iterations and was found to have a significant impact on CPU times for large 3D kinetics problems. The BiCGSTAB method was seen to be highly efficient, requiring only a few iterations per time step to solve the CMFD linear system. However, this method was only implemented for the transient solver; the steady-state solver still relied on the LSOR method, and as such, discontinuities between the steady-state and the transient were introduced.

In 2008, Information Systems Laboratories (ISL) was contracted to extend the BiCGSTAB solver to the steady-state eigenvalue problem. At this time, the Chebyshev acceleration, which was used in concert with the LSOR solver, was replaced with a more efficient Weilandt Shift eigenvalue acceleration.

Since 2008, several more nodal kinetics features and improvements have been added to RELAP5-3D. A Generalized Minimum RESidual (GMRES) solver was added along-side the BiCGSTAB solver for the CMFD solution. This GMRES solver guarantees convergence for most cases that are difficult to solve. This is a useful addition for input models which feature large flux gradients within the reactor core. In addition, a Triangular Polynomial Expansion Nodal (TPEN) method was implemented as an available nonlinear nodal solver for hexagonal geometries. The nonlinear nodal solver obtains a higher-order intra-nodal flux solution and provides a more accurate estimate of the neutron current at node boundaries. Previously, a Nodal Expansion Method (NEM) solver was utilized to improve the neutron current estimate at node boundaries. This method performed well, but tended to break down because of singularities that arise near the vertex of a hexagon. These singularities are removed with the TPEN solver, and thus a more robust solution is possible.

Other useful feature additions include a rod cusping correction treatment to handle the distortion of the flux near the tip of a control rod absorber, and a reactivity feedback method to compute the separate effects from various feedback mechanisms including Doppler temperature, moderator density and temperature, boron concentration, Xe/Sm concentration, and control rod position. In addition, the number of neutron energy groups for the new Krylov solver was extended from two to four.

Most recently, the nodal kinetics memory structure was redesigned to remove the old 1D container array previously used to store all the nodal kinetics array information. The new memory structure now relies on allocatable arrays and pointers, which improves the code readability and maintainability. In addition, an asynchronous time step control algorithm was implemented in order to advance the thermal-hydraulics and neutronics solvers independently. This is useful for cases where either the thermal-hydraulics or neutronics condition is not changing very much relative to the other. In these cases, the CPU performance can be improved by allowing the neutronics solution to run at a larger time step size than the thermal-hydraulics solution, or vice-versa.