Status of the PIES 3D Equilibrium Code*

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PIES is a 3D, free-boundary, equilibrium code that can handle islands and stochastic regions. We discuss the present status of the code, focusing particularly on improvements that have been made over the last few years.

PIES solves the 3D MHD equilibrium equations in the form:

$$\nabla \times \mathbf{B} = \mathbf{j}(\mathbf{B}), \qquad (1)$$

where $\mathbf{j}$ is a function of $\mathbf{B}$ determined by

$$\mathbf{j}_\perp = \mathbf{B} \times \nabla p / B^2, \;\; \mathbf{B} \cdot \nabla (j_\parallel / \mathbf{B}) = -\nabla \cdot \mathbf{j}_\perp. \qquad (2)$$

Contemporary stability codes that derive their input from other 3D equilibrium codes typically recalculate $j_\parallel$ using Eq. (2) to improve the accuracy of the solution for the current. PIES obtains a self-consistent equilibrium using this accurate determination of the current. The magnetic differential equation of Eq. (2) is solved in PIES by a transformation to magnetic coordinates on the KAM surfaces, and two options for calculating magnetic coordinates have been implemented, one using field line following and the other using a Newton Scheme.

In its original form, the PIES code solved Eq. (1) using underrelaxed Picard iteration. In recent years, the code has been modified to provide two additional options for solving Eq. (1). A Newton algorithm requires the evaluation of all of the terms of the full Jacobian, but its inherent parallelism and rapid convergence make it a potential option for calculations on massively parallel computers. For calculations with smaller numbers of processors, a Jacobian-Free Newton-Krylov (JFNK) algorithm has been implemented, along with an adaptive preconditioner. The Newton algorithms are globalized by backtracking, using the Dennis-Schnabel algorithm. For the JFNK approach, a subspace-restricted version of this algorithm has been developed.

An adaptive grid for calculating the current has also been implemented in recent years. This allows a more accurate treatment of the physically important current near the island separatrices. It also provides a more accurate treatment of the effects of modified bootstrap currents in magnetic islands, which are the origin of the neoclassical tearing effects, and in particular of the neoclassical tearing mode (NTM).

In recent years, a theory of equilibria in stochastic regions has been developed, and a version of the corresponding algorithm has been implemented in the PIES code.[2] This has been motivated by indications in contemporary stellarator experiments that there are large stochastic regions with significant nonzero pressure gradients.

[1] D. Raburn, Ph.D. Thesis, Princeton University, 2011.
[2] A. Reiman, M. Zarnstorff, D. Monticello, A. Weller, J. Geiger, and the W7-AS Team, Nucl. Fusion **47**, 572-578 (2007); J. Krommes and A. Reiman, Phys. Plasmas **16**, 072308 (2009).

* Work supported by DOE contract DE-AC02-09CH11466.