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Fast evaluation of the bootstrap current in stellarators

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In order to be candidates to fusion power plants, stellarators must be optimized, i.e. the magnetic field needs to be tailored to have sufficiently good confinement properties. When the optimization process is performed to minimize neoclassical losses, the goal is to obtain a magnetic field that is close to omnigeneity. A magnetic field is omnigenous [1] if the radial drift of collisionless particles averages out to zero, leading to levels of neoclassical transport similar to those in a tokamak. Quasi-isodynamic (QI) configurations are a subclass of omnigenous magnetic fields that have poloidally closed contours of the magnetic field strength, which grants them the additional property of having zero bootstrap current [2]. The bootstrap current can alter significantly the equilibrium magnetic field and, in particular, the geometry of a divertor relying on a specific structure of magnetic islands. In order to obtain a magnetic configuration with a viable island divertor, the bootstrap current must be kept sufficiently small, and this is typically ensured if the configuration is close enough to quasi-isodynamicity. Wendelstein 7-X is based on the concept of quasi-isodynamicity and has an island divertor. Another subclass of omnigenous magnetic fields consists of quasi-symmetric (QS) configurations. For QS stellarators, the bootstrap current is not small and therefore its effect must be explicitly considered during the optimization process [3].

Taking into account the bootstrap current in the optimization loop demands fast and accurate calculations at low collisionality, the relevant conditions in the core of reactor-relevant plasmas. However, accurate computations in these regimes are difficult (the exception are precisely QS stellarators, for which analytical formulas exist [3]). When the mean free path is long, boundary layers appear at the interfaces of different classes of trapped particles, and very high resolution in velocity space is required to solve correctly these boundary layers.

In this conference contribution we present MONKES (MONoenergetic Kinetic Equation Solver), a new neoclassical code for the evaluation of monoenergetic transport coefficients in large aspect ratio stellarators and tokamaks with broken symmetry. The code is spectral in the spatial and velocity coordinates, and employs a block tridiagonal algorithm for solving the resultant linear system of equations. MONKES is memory efficient and can run in a single core. It solves the same equation as the standard stellarator neoclassical code DKES [4], but it is more accurate and faster. This is demonstrated through a careful convergence study and a benchmark with DKES and SFINCS [5]. The above features make MONKES ideally suited for its integration into stellarator optimization suites. Apart from this, MONKES, complemented with KNOSOS [6,7], can be applied to a range of problems, such as the analysis of experimental discharges and predictive transport simulations.

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