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Robust stellarator optimization via flat mirror magnetic fields

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Stellarator magnetic configurations need to be optimized in order to meet all the required properties of a fusion reactor. The stellarator Wendelstein-X (W7-X) was optimized to be approximately quasi-isodynamic (QI). In an exactly QI field, trapped particles orbit, on average, in the poloidal direction, and therefore remain confined [1]. Neoclassical transport is thus expected to be low. Although the performance of W7-X has proven the success of neoclassical optimization [2], some issues remain open, such as fast ion losses and turbulent transport.

In this work, we present the concept of flat-mirror quasi-isodynamic stellarators [3]. We show that a nearly QI configuration with sufficiently small radial variation of the mirror term can achieve small radial transport of energy and good confinement of fast ions, even if it is not very close to exact quasi-isodynamicity, for a wide range of plasma scenarios (including low β and small radial electric field). This opens the door to constructing better stellarator reactors, that would be easier to design (as they would be robust against error fields) and to operate (since, both during startup and steady-state operation, they would require less auxiliary power, and the damage to plasma-facing components caused by fast ion losses would be reduced).

The properties of a flat-mirror QI field can be understood in terms of the orbit-averaged drifts of trapped particles in the tangential and radial directions, which are connected to the radial and tangential derivatives of the second adiabatic invariant J, respectively. We have identified a strategy (small radial variation of the mirror term) to approach exactly QI magnetic fields that fulfill the maximum-J property in vacuum. This is expected to have a beneficial impact on turbulence [4] and keeps neoclassical confinement good irrespective (to some extent) of the existence of a magnetic drift in the radial direction, of β and of the radial electric field. We confront this strategy with the results obtained in the optimization campaign that led to the design of CIEMAT-QI [5], a stellarator magnetic configuration with excellent properties of bulk (neoclassical and turbulent) and fast particle transport at low β.

References:

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