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Improving Energetic Particle Confinement in Stellarator Reactors

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Improving Energetic Particle Confinement in Stellarator Reactors

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Energetic particle confinement is a key issue for the scalability of stellarators to fusion power plants. Prompt losses of alpha particles born from fusion reactions can cause significant material damage. Analytically derived proxies for collisionless energetic particle confinement (1) have been used for the first time to optimize quasihelically symmetric stellarator equilibria (2). This paper will expand on recently published results, along with inclusion of analysis to account for collisional alpha particle transport with reactor relevant alpha sourcing profiles.

A proxy for energetic particle transport, γ_c, accounts for both the net bounce-averaged radial particle drifts, a quantity to be minimized, and poloidal drift, a quantity to be maximized. Minimization of c corresponds to aligning contours of the second adiabatic invariant, $J_{||}$, to flux surfaces. This metric has been included in the ROSE optimization code (3) and used to optimize equilibria for good energetic and neoclassical particle transport. Previous results indicate that two classes of stellarators, quasihelically-symmetric stellarators, and maximum-J stellarators should have better energetic particle transport than other configurations (4). This paper focuses on optimizations of quasihelically symmetric stellarators. Results indicate the existence of equilibria which nearly eliminate all collisionless losses within the plasma mid-radius (figure 1a) for an ARIES-CS scale reactor (450 m3, 5.8 T). These configurations are obtained by optimizing simultaneously for γ_c and a metric for quasihelical symmetry. Interestingly, configurations with improved energetic particle transport did not correlate with improvements to neoclassical transport in the 1/ regime as measured by ϵ_{eff}.

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It is well known that the ripple associated with realistic plasma coils can negatively affect alpha particle confinement. However, using coil optimization codes REGCOIL (5) and FOCUS (6), we show that it is possible to reproduce configurations with high enough fidelity that the alpha particle confinement is not significantly degraded (figure 1b). A key feature for the coil optimization is the realization of the equilibria with coils placed farther from the plasma, thus reducing high order harmonics associated with the toroidal mode numbers equivalent to the coil number. These high order modes have been previously found to be deleterious to energetic particle confinement on both stellarators and tokamaks.

New results will be presented regarding alpha particle transport that include collisions with the background plasma. Collisional calculations require additional assumptions about configuration parameters, most importantly the density and temperature profiles which govern the collisional equations and the alpha particle source distribution. We show that when including collisions, configurations exist at the ARIES-CS scale and with ARIES-CS parameters with total energy loss below 4% (figure 2a) with most of the losses occurring from particles born outside the midradius (> r/a = 0.55) (figure 2b). Results will be presented that show energetic particle transport under a variety of density and temperature profile assumptions.

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In light of these results, the outlook for energetic particle optimization for quasihelical stellarators is bright. The results presented here represent only a first attempt and with improved optimization algorithms better configurations may yet be found. Additionally, further improvements in stellarator coil design can help gain confidence that such configurations are realizable.

References:

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