Physics Optimization of a Quasi-Omnigeneous Stellarator*

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In quasi-omnigeneous (QO) stellarators, bounce-averaged particle drift surfaces are approximately aligned with magnetic surfaces to reduce neoclassical energy transport. This approach has the potential for a compact stellarator with good confinement, high beta, and a small bootstrap current compared to symmetric systems. Three and four field period (N_{fp} = 3, 4) QO configurations have been optimized with respect to bounce-averaged omnigeneity (B_{min}, B_{max}, J*), global magnetic well and Mercier stability, amount of plasma (bootstrap) current, magnetic field ripple, rotational transform profile È(r), while keeping the plasma aspect ratio $R_0/a_p < 4$. Confinement of near-perpendicular particles corresponding to minority-species ICRF heating, stability to ballooning modes, and the amount of bootstrap current were subsequently evaluated for these configurations. Nonplanar modular coil configurations with adequate distances between the plasma and the coils and between adjacent coils for heating and diagnostic access were then found that accurately recreated the desired magnetic configuration.

Typical QO parameters are R_0/a_p = 3.6, È(0) = 0.55, and È(a_p) = 0.64 for N_{fp} = 3 and R_0/a_p = 4.2, È(0) = 0.68, and È(a_p) = 0.78 for N_{fp} = 4. These configurations are effectively hybrid stellarator configurations that have a strong helical axis component similar to HSX and a bumpy (mirror) field component like W7-X, but at an aspect ratio which is a factor of 2-3 smaller. The calculated diffusivities and energy confinement time show a strong dependence on the radial electric field with $\tau_E^{neo}/\tau_E^{ISS95}$ = 2-3 for typical values of the ambipolar electric field. The loss rate of energetic (20 keV) trapped particles is similar to the slowing down rate for the N_{fp} = 3 case at B = 1.5-2 T and the N_{fp} = 4 case at B = 1 T. Confinement of alpha particles in a reactor would be better because reactors are larger in terms of gyroradii and prompt orbit losses are related to the degree of nonadiabaticity. The È and J* surfaces are not strongly modified by expected bootstrap current levels, suggesting a robust magnetic field structure. These configurations are stable to ballooning and Mercier modes for β up to 3% for fixed pressure profiles.

The ballooning stability calculation has been recently included in the configuration optimization loop and initial results indicate that higher beta limits should be accessible. Earlier reactor-scale QO configurations had β up to ≈7%, good confinement, and a low bootstrap current contribution to È, but were not self-consistent or optimized for a modest-scale experiment. Calculation of the bootstrap current is being inserted into the optimization loop to allow self-consistency of the current as part of the optimization procedure.

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