PHYSICS ISSUES FOR A VERY-LOW-ASPECT-RATIO QUASI-POLOIDAL STELLARATOR (QPS)*

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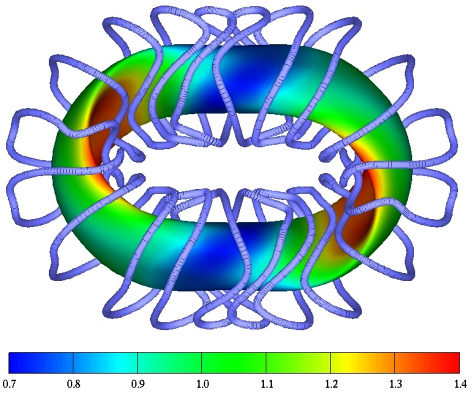
A quasi-poloidal stellarator with very low plasma aspect ratio ($<R>/<a> \sim 2.7$, 1/2-1/4 that of existing stellarators) is a new magnetic confinement approach that could ultimately lead to a high-beta ($<\beta> = 7\text{-}15\%$) disruption-free compact stellarator reactor. In this approach the dominant components in the magnetic field spectrum are poloidally symmetric in flux coordinates. The quasi-poloidal symmetry leads to small $\mathbf{B}\times\nabla B$ drifts out of a flux surface and reduced neoclassical transport, reduced flow damping in the poloidal direction; and reduced bootstrap current. The reduced bootstrap current leads to high-β MHD stability limits.

The Quasi-Poloidal Stellarator

The Quasi-Poloidal Stellarator (QPS) [1] shown in Fig. 1 is being developed to test key features of this approach. The main QPS parameters are $<R> = 0.9$ m, $<a> = 0.33$ m, $<B_{\text{axis}}> = 1$ T for a 1-s pulse, and $P_{\text{heating}} = 1\text{-}3$ MW. The shape of the QPS flux surfaces varies from bean-shaped at the higher-field ends to D-shaped in the middle of the long straight sections. In the plasma core ($r/<a> < 1/2$) the magnetic energy in non-poloidally symmetric field components is <10% of that in the poloidally symmetric field components and rises to ~30% at the plasma edge.



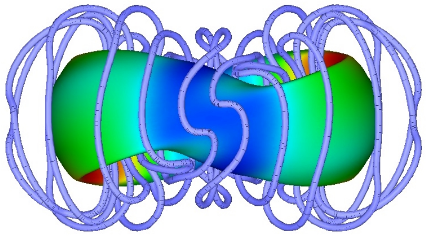


Fig. 1. Top (left) and side (above) views of the QPS plasma and the modular coils that create it. The colors indicate contours of |B| in T on the last closed flux surface.

A measure of the reduction in neoclassical transport is shown in Fig. 2. For $E_r = 0$ in the low-collisionality limit, the neoclassical ripple-induced heat diffusivity is proportional to $\varepsilon_{\text{eff}}^{3/2}$ where ε_{eff} is the effective ripple in a single helicity $1/\nu$ transport model that gives the same transport as a full 3-D calculation in this limit. QPS has similar transport to that in the W 7-X configuration, but at 1/4 the plasma aspect ratio. The quasi-poloidal symmetry and the reduced effective field ripple may also produce reduced poloidal viscosity, enhancing the naturally occurring $\mathbf{E}\times\mathbf{B}$ poloidal drifts for possible shear damping reduction of anomalous transport.

The QPS magnetic configuration is relatively insensitive to increasing β. The plasma is Mercier stable for <β> ~ 2.5%. Kink and vertical modes are stable at <β> ~5% without feedback or close conducting walls. The MHD stability limit for QPS is theoretically set by infinite-n ballooning modes at β~ 2%. However, a region of second stability at higher β exists in QPS. As β is increased above 2%, the plasma becomes ballooning unstable. At higher β (β> 6%), the core plasma enters a region of second stability. This region of second stability grows as β is increased. At the highest β (β = 9.6%) only a few surfaces near the edge remain ballooning unstable.

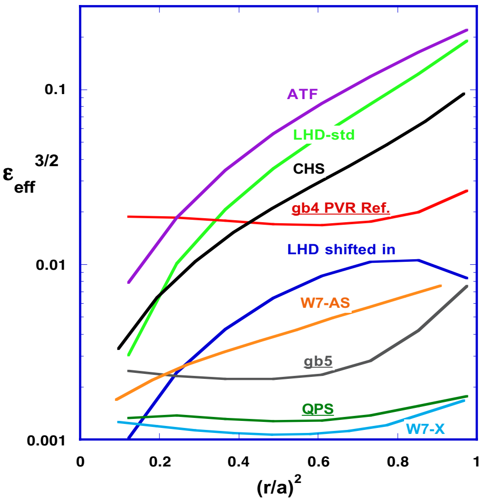


Fig. 2. $\varepsilon_{eff}^{3/2}$ *for different stellarators.*

High-β Quasi-Poloidal Hybrid Configurations

Another type of qps configuration is very-high-β hybrid configurations with a tokamak-like rotational transform profile [2] in contrast to the stellarator rotational transform profile of QPS. Figure 3a shows the last closed flux surfaces for a three-field period hybrid qps configuration with A = 3.7 and β = 15%. The colors indicate contours of constant $|B|$. Contours of $|B|$ in Boozer coordinates are shown in Fig. 3b for the $(r/a)^2$ = 0.75 surface which display the qps symmetry of this configuration. The high-β qps configurations have a high shear, tokamak-like rotational transform profile [$\iota(0)$ ~ 0.4 to $\iota(a)$ ~ 0.1] primarily from bootstrap current. The non-axisymmetric ($n \neq 0$) Fourier components of $|B|$ reduce the neoclassical bootstrap current to 1/3-1/5 that in the equivalent tokamak, resulting in stability to low-n ideal MHD kink modes for high values of β, up to β = 11% for kink and vertical stability. At this value of β, the Troyon factor β_N = 19 is significantly larger than the β_N ~ 3 for kink stability in an equivalent tokamak with no wall stabilization. The infinite-n ballooning and Mercier stability β limit for these qps configurations is very high: Mercier and ballooning-stable configurations with self-consistent bootstrap current were found for plasmas with 2% < β < 23%.

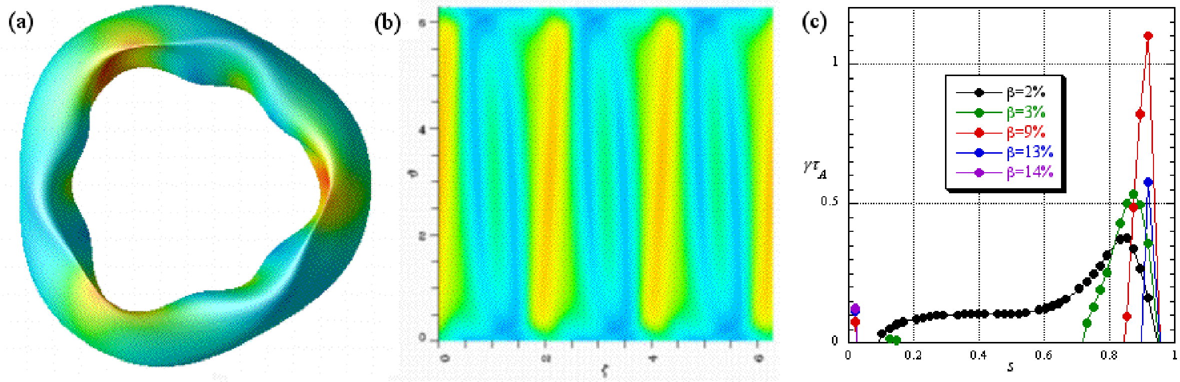


Fig. 3. (a) The last closed flux surface of a three-field period, β = 15%, A = 3.7, qps configuration with (b) contours of |B| in Boozer space for the $(r/a)^2$ *= 0.75 surface and (c) normalized ballooning growth rates for a range of β.*

[1] J. F. Lyon and the QPS team, "QPS, A Low Aspect Ratio Quasi-Poloidal Concept Exploration Experiment", http://qps.fed.ornl.gov/, April 2001.

[2] A. S. Ware, et al., “High-β Equilibria of Drift Optimized Compact Stellarators”, submitted to Phys. Rev. Lett. (2002).

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