BRIEF COMMUNICATION

Improvement of Collisionless Particle Confinement in a Non-quasisymmetric Stellarator Vacuum Magnetic Field

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Abstract

A non-quasisymmetric stellarator vacuum magnetic field with aspect ratio of about 11 is found in which collisionless particles are confined up to about 2/5 of the minor radius.

In conventional stellarator vacuum fields collisionless particles are lost through a loss cone. Quasi-symmetric stellarators can confine collisionless particles well [1]. In quasi-isodynamic stellarator vacuum fields a reduced loss cone persisted [2]. Here, by improved computational optimization of collisionless particle confinement, a non-quasisymmetric configuration is found in which the loss cone is eliminated in the core of the confinement region.

The optimization procedure used is essentially the same as in earlier efforts [2]. Additional ingredients here are a weighting procedure which strongly emphasizes early lost particles, an iterative increase of the radius where the particles are started, usage of up to 10^5 particles and a parallelized optimization procedure. The initial configuration was an interpolation between a low-β quasi-isodynamic configuration with poloidally closed contours of its field strength with very low bootstrap current [3] and the old case optimized for collisionless particle confinement [2]. Except for this latter property the optimization was unconstrained. It was terminated when about 0.4 of the minor radius was reached to assess its other properties so that modified goals can be formulated. The results are described below.

In a device with the physical parameters of W7-X (volume $\approx$ 25m^3, magnetic field $\approx$ 2.5 T) less than 1 per mil of 100keV protons started at about 0.4 of the minor radius are lost up to 0.1 s. Since this result was obtained in a zero - β VMEC equilibrium it is amenable to an independent test in a vacuum magnetic field given by a set of harmonic functions [4] satisfying the Neumann boundary condition at the VMEC boundary. The VMEC result was essentially verified by following α-particles in the

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vacuum field scaled to fusion dimensions (volume 10^3m^3 , magnetic field 5 T). From the 1000 particles started and followed up to 0.1 s, four particles were lost between 0.003 and 0.01 s.

Views of the geometry of the configuration and its structure of the field strength is seen in Figs. 1 - 3 as obtained by VMEC. Overall, it is close to a quasi-isodynamic configuration with poloidally closed contours of the field strength [5]. In more detail, the poloidal closure of the contours of the field strength is less perfect near the maximum of B on a magnetic surface, which, as in W7-X, occurs on the inner side of the torus. A particular feature is seen in the surfaces of the field strength: while these are convex (see Fig. 2) as seen from the minimum of B located in the triangular flux surface cross-section (as is in accordance with the fact that a true-minimum B on the magnetic axis is not found in toroidal vacuum fields) they become concave (see Fig. 3) near the maximum of B. This suggests a minimum-J (with J the second adiabatic invariant) situation near the minimum of B and a maximum-J situation near the maximum of B, as are indeed found upon inspection of the J-contours. Accordingly, the neoclassical ripple and bootstrap current coefficient are small: in comparison to the results in [3], the ripple is smaller and the magnitude of the bootstrap current coefficient about three times larger than the corresponding values for the quasi-isodynamic case.

Since the overall geometry of the configuraton was changed so little (see Fig. 13 in[5]), other global properties changed little, too. The magnetic well is about 0.012, the rotational transform profile is seen Fig. 4 with the 5/5 resonance occurring at about 0.85 of the minor radius. In Fig. 5 magnetic surfaces of the configuration are shown and the width of the 5/5 islands is seen to be about 0.07 of the minor radius as obtained by solving the vacuum-field Neumann problem at the VMEC boundary.

Future work may try to find a configuration with similar properties but reduced aspect ratio of the 5/5 island chain.

Acknowledgments

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Figure captions

Fig. 1. Boundary magnetic surface of the optimized configuration also showing the magnetic topography, i.e., the strength of B on this surface.

Fig. 2. Near-axis magnetic surface and two surfaces of constant B near the minimum of B.

Fig. 3. Near-axis magnetic surface and surfaces of constant B near the maxima of B.

Fig. 4. Rotational transform profile vs. normalized small radius.

Fig. 5. Magnetic surfaces at the triangular and crescent-shaped cross-sections. Red points refer to normalized minor radii 0.4 and 0.5, and to island surfaces.

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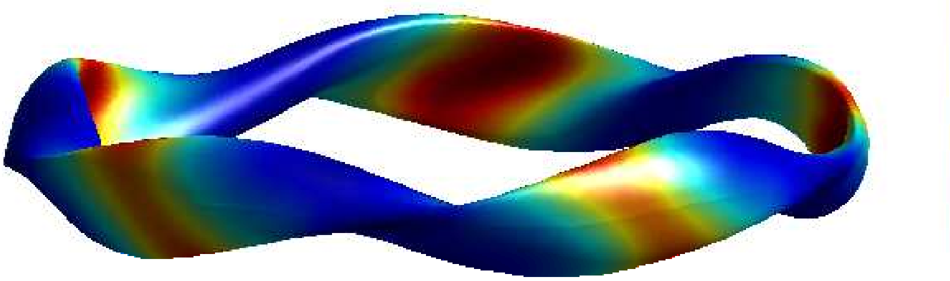

Figure 1

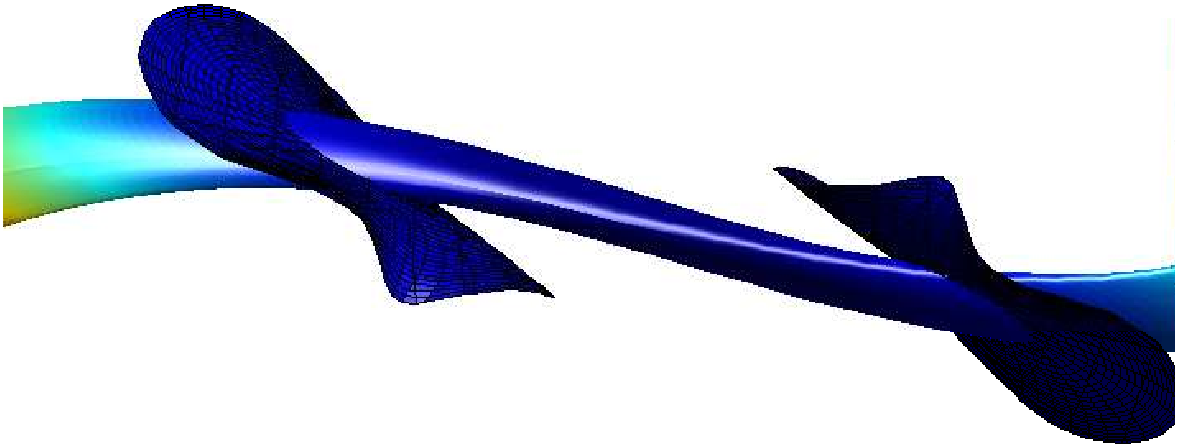

Figure 2

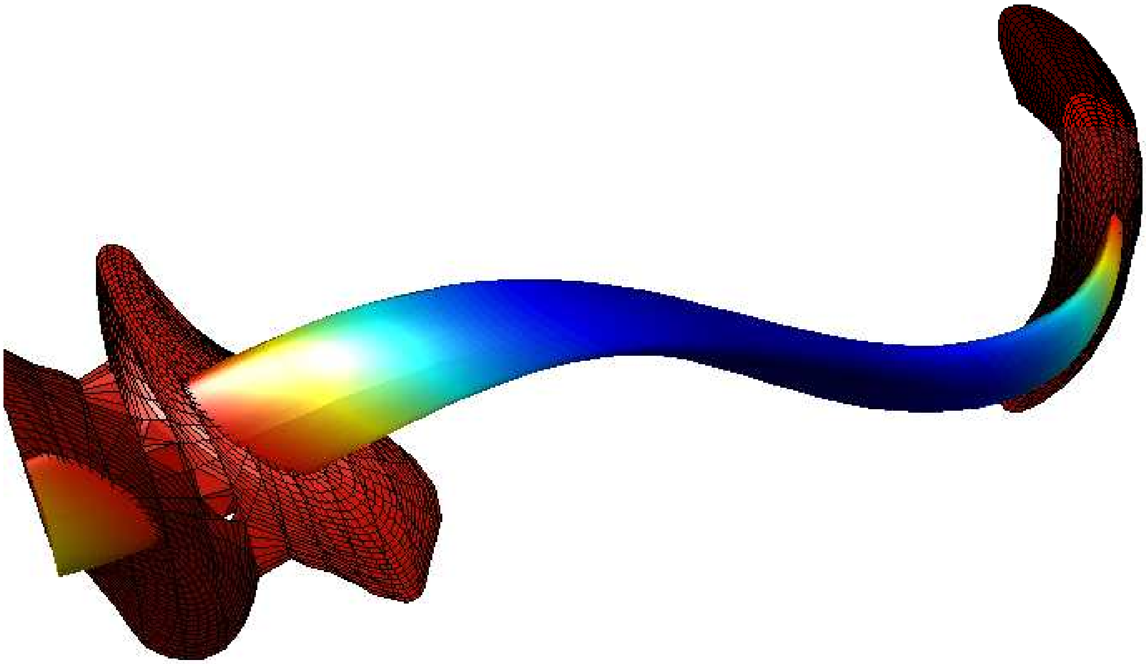

Figure 3

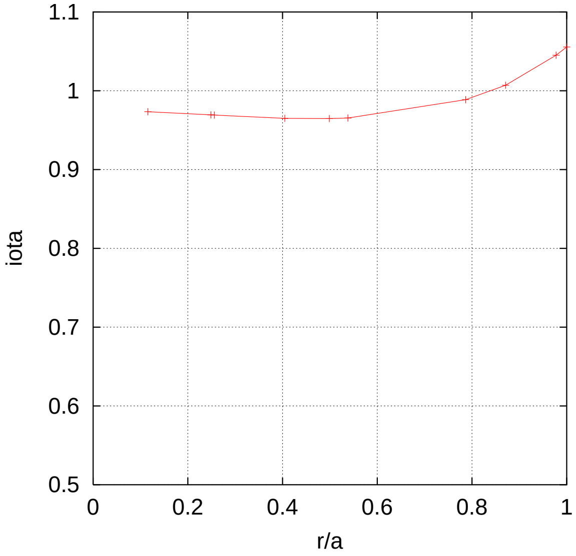

Figure 4

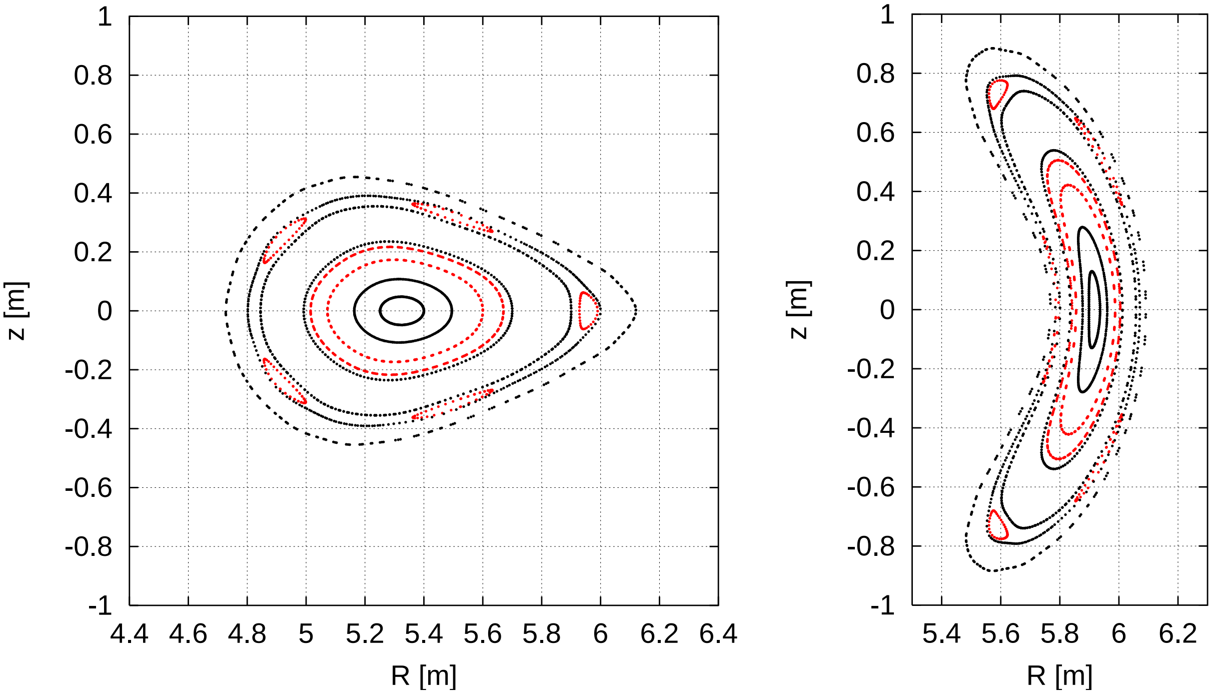

Figure 5