Shaping Stellarators to Reduce Turbulent Transport

Two recent numerical tools combine to permit designing stellarators and other toroids to minimize turbulent transport

There are two general mechanisms of plasma transport in magnetic confinement devices, one due to collisions between particles, and the other due to plasma turbulence, which permit particles to diffuse out of the device. Since the inception of the fusion program in 1950s, transport due to turbulence has been a dominant challenge for enabling these devices to contain plasmas long enough that fusion can take place. Beginning in the 1980s, advances in the shaping of stellarators, the nonaxisymmetric toroidal devices first introduced in the 1950s, have radically reduced the levels of collisional transport, leaving turbulent transport as the principal loss channel in both stellarators, and in tokamaks, their axisymmetric cousins. Despite this, also designing these devices to reduce turbulent transport has not been addressed, due to the notorious complexity of turbulent transport.

Recently, however, two powerful numerical tools have become available, which allow 3D shaping to also minimize turbulent transport a realistic possibility, *viz*, codes for 3D nonlinear gyrokinetic simulations, such as GENE[1,2], and stellarator optimization codes such as STELLOPT[3].
New theoretical work[4] by scientists at the Princeton Plasma Physics Laboratory (PPPL) and the Institute for Plasma Physics at Greifswald, Germany (IPP-Greifswald) have extended the cost function of STELLOPT to also include a measure for turbulent transport, and using it and GENE simulations to gauge the turbulence properties of the configurations generated, have found "proof of principle" configurations having turbulent transport substantially reduced from that in the initial configurations to which the optimizer was applied,

Shown in Fig.1 is a comparison of cross sections of the initial (black) and one final (red) stellarators at several positions around the "donut". In Fig.2 is plotted the radial heat flux Q(t) computed by GENE for these 2 devices versus time. The evolved configuration shows averaged transport levels reduced by a factor of about 2 below that of the initial configuration (the NCSX "quasi-axisymmetric" stellarator design, already optimized for collisional transport), a reduction comparable to that achieved in going from "L-mode" to "H-mode" in tokamaks, which provides a major advance in tokamak operation.

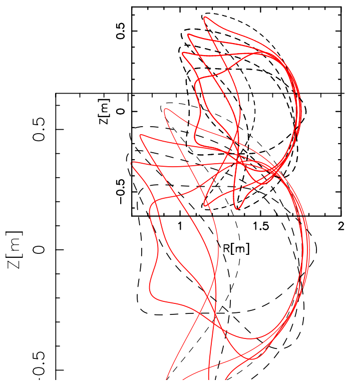

Fig.1. Cross sections of original (black) and evolved (red) stellarator configurations at several toroidal angles.

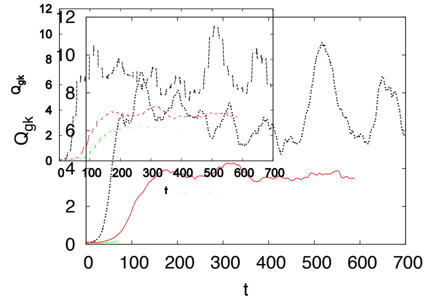

Fig.2. Radial heat flux versus time from gyrokinetic simulations for original (black) and evolved configurations.

The method established in [4] should be readily applicable to reducing transport due to turbulent transport channels other than the "ion temperature gradient" turbulence captured by the present model, as well as to reducing the turbulence in other starting devices, including other interesting stellarator designs, and possibly in tokamaks as well.

[1] F. Jenko, W. Dorland, *et al.*, Phys. Plasmas 7, 1904 (2000).

[2] P.Xanthopoulos, W.Cooper *et al.*, Phys.Plasmas 16, 082303 (2009).

[3] A. Reiman, G. Fu, S. Hirshman, L. Ku, *et.al*, Plasma Phys. Control. Fusion 41 B273 (1999).

[4] H. Mynick, N. Pomphrey, P. Xanthopoulos, Phys. Rev. Letters 105, 095004 (2010).