Robustness and Flexibility in NCSX: Global Ideal MHD Stability and Energetic Particle Transport

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Abstract

Concerns about the flexibility and robustness of a compact quasiaxial stellarator design are addressed by studying the effects of varied pressure and iota profiles. For thirty related equilibrium configurations the global, ideal magnetohydrodynamic (MHD) stability is evaluated as well as energetic particle transport. It is found that tokamak intuition is useful to understanding the MHD stability, with pressure gradient driving terms and shear stabilization controlling both the N=0 and N=1 unstable modes. Global kink modes are generated by steeply peaked profiles and edge localized modes are found for plasmas with edge iota above 0.5. Energetic particle transport is not strongly dependent on these changes of pressure and iota profiles, although a weak inverse dependence on pressure peaking through the magnetic axis Shafranov shift is found. While good transport and MHD stability are not anticorrelated in these 30 equilibria, stability depends on a delicate balance of the pressure and shear stabilization forces.

1. Introduction

An intense effort to achieve a stable and well confined compact quasiaxial stellarator (QAS) configuration has led to a promising design for the NCSX device [1]. The global, ideal magnetohydrodynamic (MHD) stability of quasiaxial stellarator designs for NCSX is being evaluated with the three-dimensional stability code packages CAS3D [2] and TERPSICHORE [3]. Recently CAS3D has verified and extended calculations [4] of the TERPSICHORE code, showing stability of the nonperiodicity-preserving kink (N=1) and periodicity-preserving (N=0) modes for the proposed stellarator, even without a conducting wall [5]. Particle transport is also being examined with ORBITMN [6] and related codes. Here we examine the effect of variations of the pressure and iota profiles on the MHD stability and energetic particle transport of NCSX, maintaining the boundary shape and the average beta fixed at 3.8%.

2. Pressure and iota profile variations

To assess flexible performance in a modest-sized experiment, the VMEC code [7] is used to obtain equilibria for 30 related equilibria exhibiting different stability and transport behaviors. The plasma equilibria obtained are designated P0X/I0Y as follows: P00/I00 is the baseline QAS3_C82 configuration. P01, P02 and P03 were defined so that P01 is similar to P00, P02 is more peaked than P01, while P03 is broader than P01. P04 is a very broad, parabolic pressure profile and P05 is the pressure profile used in the Helias reactor studies based on W7-X design. The iota profiles are chosen as follows: I01 is linear, maintaining $\iota(0)$ and $\iota(a)$ the same as in I00. I02 and I03 are based on I01 and also keep $\iota(0)$ and $\iota(a)$ as in the baseline case, but with increased edge shear by a factor of 1.5 and 2, respectively. I04 is a linear iota profile with $\iota(0)$ as for the other profiles but $\iota(a)$ higher than 0.5.

3. Stability of the External Kink and Periodicity-Preserving Modes

Most of the stability calculations for these pressure and iota scans were obtained with the TERPSICHORE code, with a pseudoplasma approximation for the vacuum region, setting the wall distance at 1.5 minor radii away from the plasma boundary. Figure 1 shows the stability of the N=0 and N=1 modes and how this depends on the pressure and iota profiles examined. For pressure profiles P00 and P04 the unstable modes found were similar for all the iota profiles. Global kink modes are generated by steeply peaked profiles near the half-radius and edge localized kink (ELK) modes are found for plasmas with edge iota above 0.5 and with a steep edge pressure gradient. These ELKs in the QAS are driven by high edge current densities, as are the edge localized modes (ELMs) in tokamak H-modes.

4. Energetic Particle Transport

In recent work with the ORBITMN code we have surveyed a variety of quasiaxial stellarators and examined thermal and energetic particle transport. Simulations for the complete sequence of equilibria, with deuterium beam ions at 40 keV and a peaked deposition profile, led to similar energetic particle losses in every case. The results of all the simulations are shown in Figure 2. The figure shows a weak dependence of the particle and energy loss fractions on the position of the magnetic axis as well as the pressure profile dependence.

There is little effect on energetic particle transport from the variations in plasma pressure and in iota.

5. Conclusions

A series of simulations and calculations varying the pressure and iota profiles for the QAS3_C82 design shows that the stability of the N=1 and N=0 families of global ideal MHD is quite dependent on the particular pressure and iota profiles chosen. Calculations for fixed edge poloidal flux and plasma boundary shape at 3.8% beta demonstrate that many of the concepts of tokamak MHD are useful in understanding how instabilities arise in QAS. Early NCSX candidate configurations, studied before finding the QAS3_C82 configuration, possessed different plasma boundary shapes and/or iota profiles and exhibited either improved kink stability or improved particle transport but not both. While good transport and MHD stability are not anticorrelated in these 30 equilibria, stability depends on a delicate balancing of the pressure and shear stabilization forces.

6. Acknowledgement

We are glad to thank R. J. Hawryluk and R. J. Goldston, Princeton Plasma Physics Laboratory, for interesting discussions. We also thank S. Hirshman, Oak Ridge National Laboratory, for use of the VMEC code and L.-P. Ku, S. Ethier and D. McCune, Princeton Plasma Physics Laboratory, for computational support.

*Supported by the US Dept. of Energy Contract DE-AC02-76CH03073.

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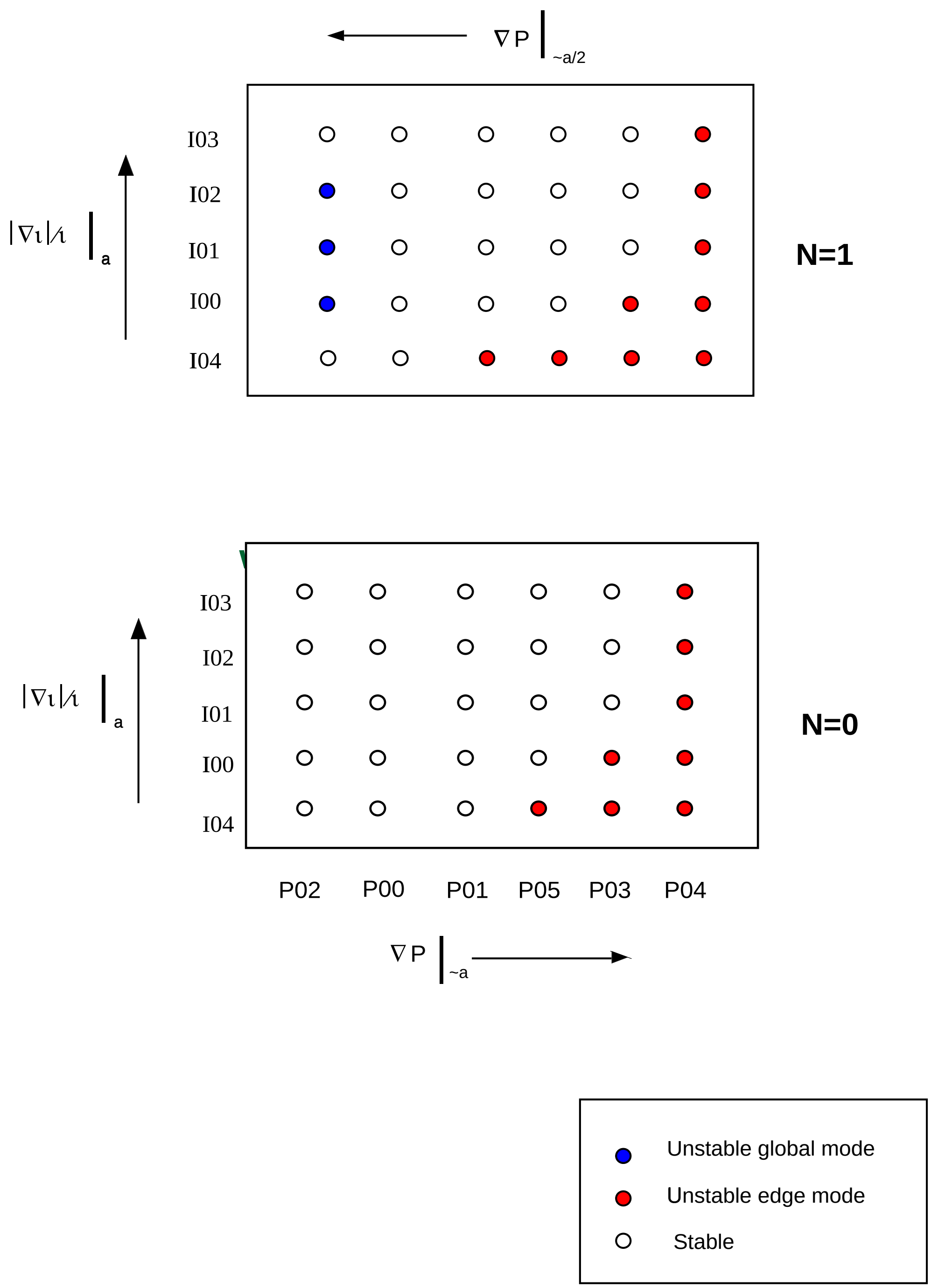

Fig. 1 Stability diagram for the N=1 and N=0 modes for 30 equilibrium configurations with varied pressure and iota profiles.

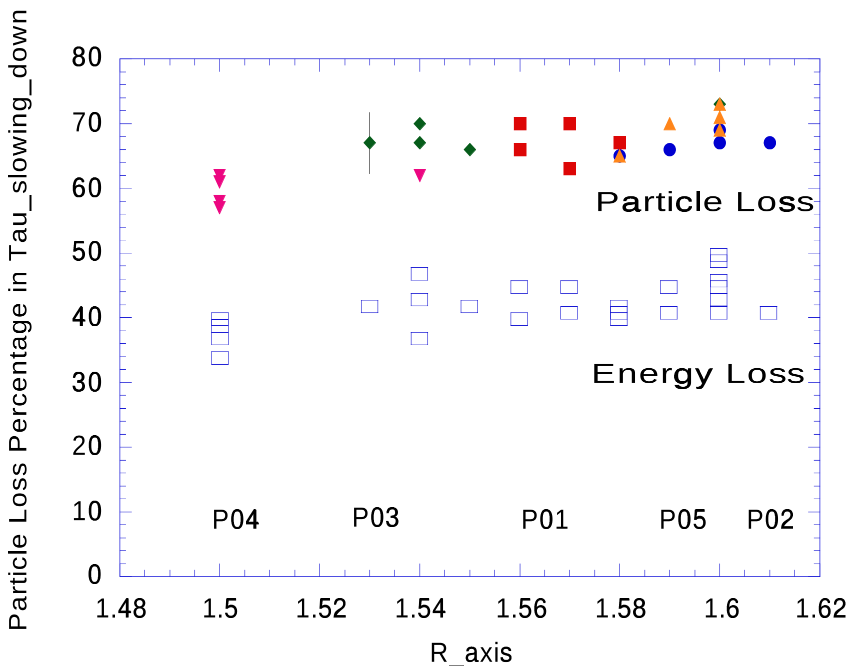

Fig. 2 Energetic particle losses and associated energy losses for 30 equilibrium configurations with varied pressure and iota profiles.