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Edge Stability of NCSX

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The ideal MHD stability of plasmas with significant edge current density is important for predicting the limiting pressure for edge transport barriers, due to the pressure-driven edge bootstrap current. The loss of edge MHD stability is consistent with the occurrence of ELM instabilities in tokamaks [1]. The sensitivity of the edge MHD stability to edge parallel current and edge pressure gradients is studied for the National Compact Stellarator Experiment (NCSX), to understand its stability characteristics.

The National Compact Stellarator Experiment (NCSX) [2], currently under construction, is a three-period quasi-axisymmetric stellarator designed to study confinement and stability of high-beta plasmas. It was numerically designed to be ideal-MHD stable at β=4.1% [3] including the self-consistent bootstrap current, using broad pressure profiles defined to not have any edge gradient, and thus no edge bootstrap current. By adjusting coil currents, stable configurations with β=6.5% have been found. To improve its stability properties, NCSX has 'reversed shear' with iota increasing from the center to the edge, strong shaping with the toroidal-average elongation $\langle \kappa \rangle$=1.8, average triangularity $\langle \delta \rangle$~1, and q(a)~1.5. NCSX was also designed with very low residual helical-ripple, and thus is expected to have reversed-shear tokamak-like transport [4] and bootstrap current providing approximately ¼ of the rotational transform.

Edge parallel current is theoretically predicted to be stabilizing in stellarators with radially increasing rotational transform [5] ('reversed shear' in tokamaks). The edge current density increases the magnitude of the edge magnetic shear, making it more strongly 'reversed' and thus more stable. This is in contrast to tokamaks, where edge current density decreases the magnetic shear, and edge current density can destabilize the peeling instability.

Expected edge stability in NCSX has been investigated in two separate numerical studies [6]. In both, free-boundary MHD equilibria for the NCSX M45 coils were calculated by VMEC [7], using broad pressure profiles. The current profile is given by the bootstrap current, calculated using low collisionality expressions [8] by the BOOTSJ code, represented as a polynomial in toroidal flux. The effect of residual helical ripple was neglected by using the equivalent axisymmetric magnetic field in the calculation. Ideal MHD stability was calculated using the COBRA code [9] for infinite-n ballooning modes, and using TERPSICHORE [10] for low to moderate-n ideal modes.

In the first study, the coil currents were optimized using the STELLOPT code to produce an equilibrium with standard profiles that was calculated to be stable with β= 5% with low effective helical ripple. The effect of edge current was studied by adding an edge current density perturbation varying as ρ^{20} while keeping the coil currents and plasma pressure fixed, where $\rho = \langle r\rangle / \langle a\rangle$ is the normalized minor radius, $\langle r\rangle$ is the local average minor radius and $\langle a\rangle$ is the edge average minor radius. The relative magnitude δ of this additional edge current was parametrically varied, as shown in Fig. 1. For all magnitudes of the edge current studied, up to approximately the cross-section average current density, the plasma is calculated to be stable at β= 5% to both low- and high-n ideal instabilities. Figure 2 shows the change in the edge rotational transform profile for a subset of the cases, showing that the edge magnetic shear increases with increasing edge current density. Thus, as predicted theoretically, edge current density does not destabilize the plasma. This raises the possibility that edge bootstrap current, generated by an edge transport barrier and pressure or pedestal, may improve MHD stability in NCSX.

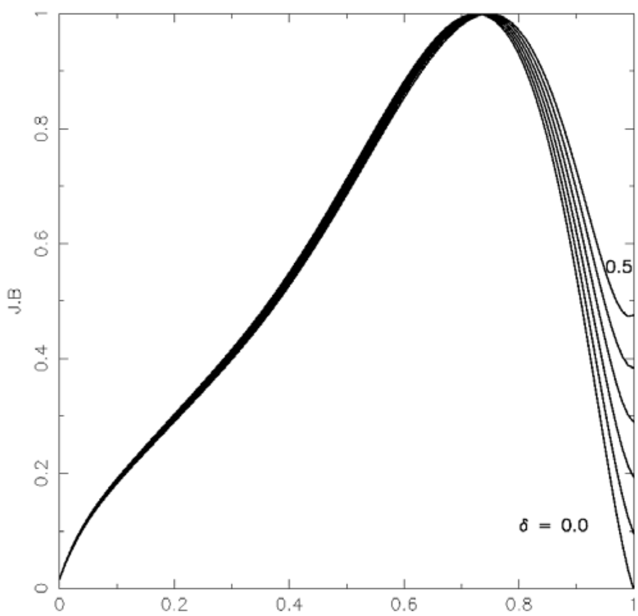

Fig. 1. Current profiles with edge perturbations, plotted versus normalized toroidal flux: s = ρ^2, for testing effect on MHD stability. δ =0 is the reference bootstrap current profile.

In the second study, the effect of finite edge pressure gradient was investigated by adding an edge perturbation to the standard pressure profile. The pressure perturbation has the form $p_{ped}\rho^{14}\left(1-\rho^{6}\right)$, where p_{ped} is the pedestal magnitude and sets the size of the edge gradient. The base profile gave β=3%. For a number of p_{ped} , values, STELLOPT was used to optimize the coil currents values to minimize the residual helical ripple while preserving ideal MHD stability. Figure 3 shows both the standard and perturbed pressure profiles for a representative case. It has

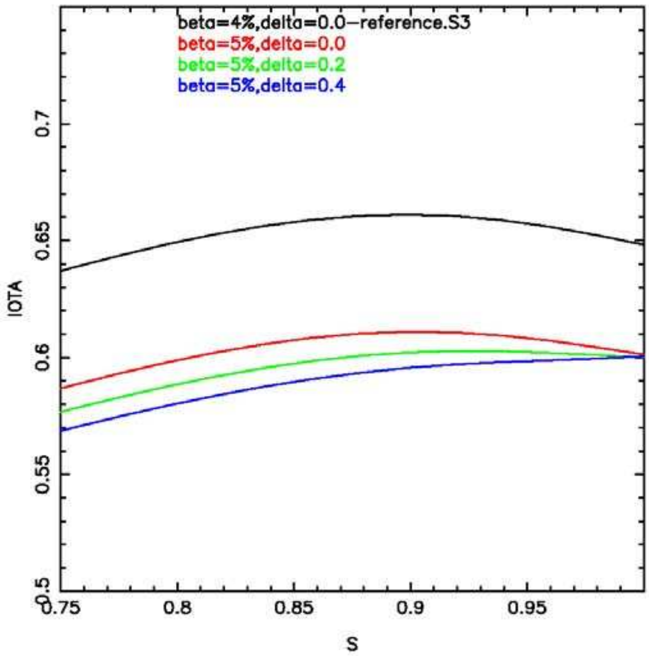

Fig. 2. Rotational transform profiles, near the edge: red - δ=0, green - δ =0.2, blue - δ =0.4, black - standard 4% case with δ =0.

$(dp/ds)\,|_{\rho=1}\,/\,p(0) = -2.8$, is calculated to be stable to ballooning and kink instabilities, and has a low effective helical ripple of 0.56% at $\rho = 0.7$.

These results indicate that NCSX should be more stable to edge current than comparable tokamaks. Edge current does not destabilize the plasma, in agreement with theoretical predictions. Strong edge pressure gradients also do not produce instability. Thus, NCSX may be stable for significant edge transport barriers and pressure pedestals, including their self-consistent bootstrap current..

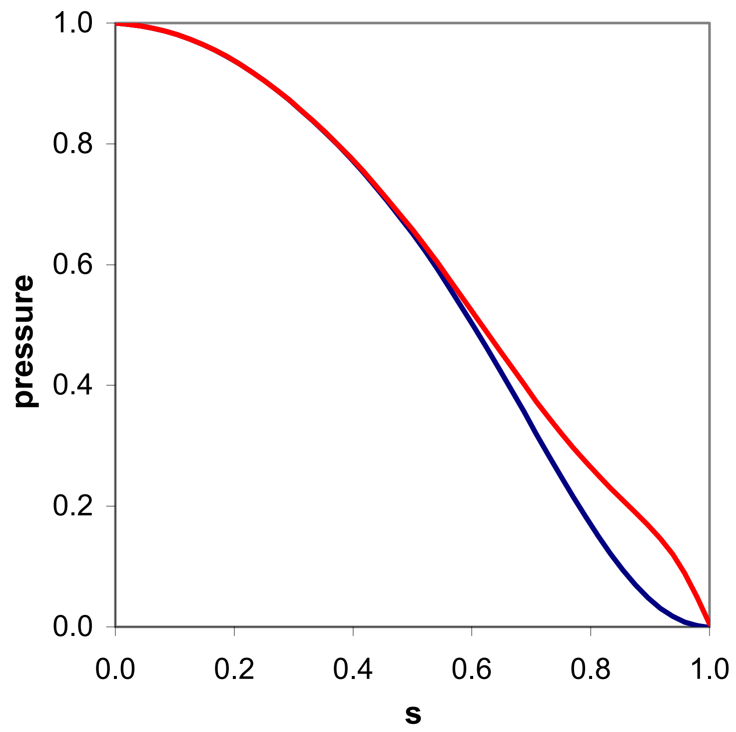

Figure 3. Profile of normalized pressure for standard (blue) and including edge pressure perturbation (red).

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