Resistive MHD Evolution of Shaped RFP Equilibria

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Resistive MHD Evolution of Shaped RFP Equilibria

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Abstract

Compared modeling of the resistive MHD evolution of reverse-Ga-pinch (RFP) plasmas with boundary shaping is underway. The VMEC code obtains equilibria that are similar to quasi-single-helicity (QSH) states in an RFP with a helical axis and a symmetric boundary [J.D. Hanson et al., Nuclear Fusion 55 (2015)]. Previous work has shown that axisymmetric shaping affects whether an axisymmetric or QSH equilibrium is obtained in VMEC, and it affects the extent of the swinging of the helical axis in the QSH state. In this work, these equilibria are used as initial conditions for the NIMROD code [J.C. Sevran, et al., Phys. Plasmas 44, 102507 (2007)]. Resistive MHD behavior will be explored and particular attention will be paid to the evolution of global tearing modes in both axisymmetric and helical boundary.

Motivation

- RFP experiments have observed quasi-single-helicity (QSH) or single-helical-axis (SHA) states that have improved confinement relative to standard helix (MH) RFP configurations
- Helical plasma with an axisymmetric boundary!
- QSH and SHA states are more likely at higher Lundquist number and higher plasma current
- Magnetic spectrum dominated by a single helicity:
  - Figure 8 from P. Martin, et al., Nucl. Fusion 43 (2003) 1855
- QSH develops when the inner-most tearing mode grows to large amplitude
- Figure from J. Ibusuki (private communication)
- Shaping the boundary has been hugely beneficial in improving stability for tokamaks – could shaping of the boundary have a beneficial impact for a reverse field pinch?
- Current RFP experiments have essentially circular boundaries
- Previous work has examined the impact of axisymmetric shaping on RFP equilibria in VMEC
- Adding ellipticity to the boundary of an RFP equilibrium results in a larger swing of the helical axis
- We are able to optimize the helical swing of the axis by changing the axisymmetric shape of the boundary
- See Poster CP11-00140 Ware, et al., for more details
- What impact does this boundary shaping have on MHD stability in these RFP equilibria?
- We can examine the effect on resistive MHD stability and dynamics using the NIMROD code

NIMROD: A resistive MHD code

- The NIMROD code uses a finite element discretization in the poloidal plane of fusion devices with a semi-implicit time step to capture the time-dependent nature of the MHD equations [See A.H. Glasser, et al., Control Fusion 44 (1999) A574-A575.]
- The 2D elements allow for arbitrary selection of cross-sections, but the Fourier series require periodic symmetry within the device
- The elements are either quadrilateral or triangular, and allow for nonlinear spacing according to flux surface, so that particular surfaces of interest may gain higher resolution
- There is a rich background of research utilizing NIMROD to model non-ideal plasmas
- The next steps involve testing the implementation of NIMROD at higher toroidal numbers, especially the n = 5 and n = 6 mode numbers, where QSH states are most commonly observed
- We will focus on fitting appropriate mesh configurations to these cases, in preparation for tests involving shaped boundaries

Shaping the boundary affects the equilibrium

- We have previously used the VMEC code to analyze RFP equilibria
  - Under certain conditions the solutions bifurcate to an axisymmetric solution or a QSH-like state with a large swing of the helical axis, depending on the initial guess of the magnetic axis

The safety factor profile of the device shown plotted against the poloidal flux

Preliminary NIMROD runs

- NIMROD uses non-ideal MHD equations with 2-fluid effects, but for the purposes of our work we limit NIMROD to the resistive MHD model
  - We have installed and compiled the main version of NIMROD on Edison
  - We have begun modifying the NIMROD code to accept either a fixed boundary or a QSH boundary

Making NIMROD to read in an RFP equilibrium from VMEC

- N. Roberds has previously modified NIMROD to read in a VMEC equilibrium to model sawtoothing in the CTH device
- Assumed a free-boundary equilibrium
  - This requires a filamentary description of the plasma coils and is incompatible with RFP solutions in VMEC (which are fixed boundary)
  - This trunk of NIMROD did not become part of the main branch
- We have begun modifying the NIMROD code to accept either a fixed or free boundary VMEC equilibrium
  - Since a fixed-boundary VMEC equilibrium does not have a representation of the coils, we must assume a conducting wall at the plasma boundary
  - No normal component of the magnetic field at the boundary and a no-slip condition
  - Our goal is to test the effects of axisymmetric shaping of the boundary on the nonlinear MHD evolution of RFP configurations

Discussion

- The mesh used in NIMROD allows for nonlinear packing which yields increased resolution at given flux surfaces, and a wide variety of cross-sectional geometries
  - The mesh is composed of triangular and quadrilateral elements, which give a great range of potential resolutions for the interpolating Lagrange elements
- We have run several linear and nonlinear tests with different mesh configurations
- Appropriate choice of packing will be crucial to high quality tests of shaped boundary cases and observations of tearing modes
- Shaping has been shown to increase the helical excursion for states with QSH, so high degrees of resolution in those regions will allow detailed examination of the evolution of these states in resistive plasmas

For further information regarding QSH states in RFPs see Urvashi Gupta at the University of Wisconsin Madison

To the left are 3 instances of the time evolution of the n = 0 toroidal mode. The left column shows the time evolution of the magnetic field strength, and the right column shows the progression of the ion velocity

As time increases the ion flows on the outer flux surfaces generates a magnetic field which increases the magnitude of the magnetic field in the core of the device

For further information regarding QSH states in RFPs see Urvashi Gupta’s poster (UP11-00003)

From these preliminary runs we also want to know how to classify the behavior we would observe, which is conventionally done by observing the safety-factor profile

The safety factor profile of the device shown plotted against the poloidal flux

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