PROGRESS REPORT
THEORETICAL REVERSED FIELD PINCH AND TOKAMAK STUDIES
November 1, 1992 to June 10, 1993
DE-FG02-85ER53212

I Fluctuation Suppression by Electrostatic Current Injection

A major goal of the MST program is to improve energy confinement in the RFP through suppression of magnetic fluctuations. It is believed that these fluctuations, which are dominated by several MHD tearing modes, can be suppressed through control of the current density profile. Theoretically, the most thoroughly investigated technique for control of the current profile and fluctuations is electrostatic current injection (often referred to as helicity injection). The principle of the technique has been established by Ho through the use of 3D, nonlinear, resistive, MHD code which self-consistently treats the fluctuations and their effect on the mean fields. This work has been extended significantly at Wisconsin to address several critical issues relevant to execution of the experiment in MST (in collaboration with D. Schnack and Y. Ho of SAIC, La Jolla).

We have studied the dependence of the fluctuation suppression technique on injector geometry, Lundquist number S , and aspect ratio A . In general, toroidally symmetric injection is optimal and produces complete stabilization over all parameter space tested (S from 1000 to 10,000 and A at $5/4$ and $5/2$). Poloidally symmetric and other toroidally localized configurations do poorly for $S > 5000$ or for realistic aspect ratio ($5/2$). The difference in performance can be attributed to power flow from the injection systems. The induced electric and magnetic field perturbations influence the Poynting flux from the injectors. To be successful, the injection system must deliver power to the mean quantities at the locations where the mean quantities would gain power from the fluctuations. Toroidally localized systems deliver power too far inward. Also, such systems will induce $m=0$ fields that may couple nonlinearly to unstable $m=2$ modes. If so, they can transfer power directly to the fluctuations instead of to the mean quantities.

Approximation of toroidally symmetric injection by a segmented configuration is a realistic compromise. Although stabilization is not complete, good magnetic surfaces are restored. The optimal realistic geometry is still being investigated, and is a critical guide for the upcoming experiment in MST.

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II Pulsed Poloidal Current Drive

To investigate the effect of current profile broadening on magnetic fluctuations, an experiment is underway in MST to drive edge current through application of a poloidal electric field. The experiment has been simulated with the nonlinear MHD code. The evolution of global parameters is similar in both code and experiment. However, detailed measurement of the edge current density profile in MST indicates faster penetration of the current in the code and there is a corresponding greater reduction of fluctuations in the code (10x) than in the experiment (2X).

III Effect of Current Drive on Fluctuations

To investigate the sensitivity of fluctuations to various current density profiles and to additional current drive techniques, we have added an ad hoc force to the electron fluid equations. The ad hoc terms appear in the MHD code in the $m=0$, $n=0$ parts of Ohm's law and the momentum equation. The mechanism of current drive is not treated. However, the self-consistent evolution of the current density profile (except for the ad hoc auxiliary driven current) and the fluctuations is treated. Completely stable profiles have been produced with the force centered at $r=0.8$ to 0.85 , with widths of 0.1 to 0.3 . Other force profile centers indicate that modes resonant inside the force location are easily stabilized, as might be expected from linear theory. Therefore, good flux surfaces in the core are produced with a deposited auxiliary power of about 10-20% of the total Ohmic power. These results encourage the investigation of current drive methods for the RFP, as described below.

IV RF Current Drive In the RFP

We have begun an investigation of rf current drive in the outer portion of the RFP for the purpose of fluctuation suppression (in collaboration with E. Uchimoto of the University of Montana). We have performed rough estimates of (1) the accessibility and ray trajectories of the fast and slow waves in MST using a cold plasma model without magnetic shear, (2) the energy deposition rate of the fast wave by using a hot plasma model, and (3) the current drive efficiency by making proper topological corrections of past tokamak results. Our early investigations focused on the frequency range between ion cyclotron and lower hybrid wave frequencies. The RFP

differs from the tokamak in that $\omega_{pe}/\omega_{ce} \approx 10$ (vs 1 in the tokamak), the magnetic curvature and shear are large, and the fraction of trapped particles is small.

A possible candidate for current drive is the fast wave in the 20-30 MHz range, launched at a 45-degree angle on a constant toroidal angle plane. In this frequency range, however, ray tracing is not reliable due to the relatively large wavelength. In addition, fast wave current drive is not yet well-established, even in tokamaks. Thus, we are extending our study to slow waves in the frequency range above 100 MHz (lower hybrid current drive). Preliminary estimates indicate that these waves can propagate to the half-radius position and that the power could be deposited in the outer half of the plasma, favorable for fluctuation reduction.

V Development of a Hyper-Dissipation Algorithm

A prevalent limitation of MHD code studies has been the inability to operate at high values of Lundquist number. For example, in the MST experiment $S > 10^6$, whereas in the code typically $S < 10^4$. To operate the code at high S , we are developing an algorithm which uses a dissipation which is realistic for wave numbers of interest and increases sharply for high k . The hyper-dissipation would transition from a k^4 dependence at high k to a k^2 dependence at low k . Linear, numerical stability analyses have been carried out in slab geometry for a semi-implicit scheme and an implicit scheme. It has been estimated that the implicit scheme can provide enough dissipation to prevent radial aliasing with 150 radial grid cells while providing an effective S of 10^6 for $k < 12\pi/a$. Work on the difference equations and the matrix inversion are beginning.

VI Interacting Magnetic Islands

Development of the theoretical paradigm of interacting magnetic island topologies of toroidal configurations is continuing. These studies are based on the idea that when local thermodynamic gradients provide a free energy source for magnetic island formation, the magnetic "equilibrium" is described by a mixture of magnetic islands, regions of magnetic stochasticity due to island interaction, and regions with "good" magnetic surfaces. In particular, bad curvature in reversed field pinch configurations allows access to pressure gradient free-energy through the resistive interchange

effect, whereas fluctuations in the bootstrap current provide an island forming mechanism in tokamaks. The envisioned magnetic topology, if operative in toroidal devices, would have an important impact on our understanding and interpretation of plasma transport properties, stability characteristics and fluctuation phenomena.

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