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Current-Profile Control and Sustainment in the MST Reversed-Field Pinch

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Introduction

Research on the MST device [1] focuses on several plasma physics topics related to improved confinement and plasma sustainment for the RFP. In this paper, Section I describes work on improved confinement by current-profile control, and Section II describes work on sustainment. Section III is a summary.

I. Improved Confinement with Current-Profile Control

The reversed-field pinch (RFP) confinement configuration has a magnetic field produced mostly by the plasma current. It can have a high beta (thermal pressure normalized to magnetic pressure) since it lacks a strong applied toroidal magnetic field. Its highly sheared magnetic-field profile includes several mode-resonant surfaces, and a sufficiently peaked equilibrium current profile can act as a linear drive source for nonlinearly coupled tearing modes, leading to widespread magnetic reconnection and field-line stochasticity. In such a case the resulting energy confinement is poor, and so a primary part of RFP research is in improving confinement by profile control to suppress tearing.

On MST the transient application of an inductive electric field (chiefly in the poloidal direction) is used to flatten the current profile, thereby reducing tearing and improving confinement [2,3]. Recent advances in improved-confinement plasmas [4] include the achievement of simultaneous, sustained high temperatures for both the electrons and ions, radial profiles of which are plotted in Fig. 1. The global energy confinement time in this case is 12 ms (compared to 1 ms for the unimproved RFP).

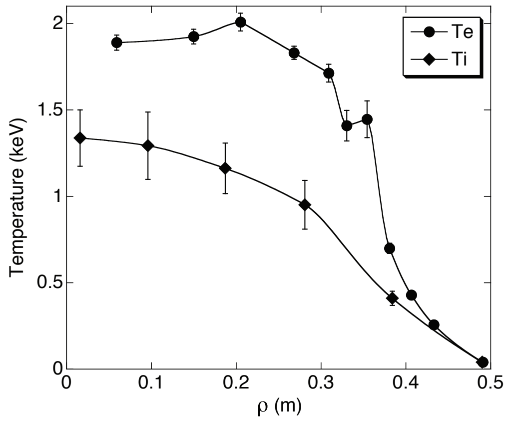

Figure 1: Electron- and ion-temperature radial profiles for recent experiments with improved confinement.

A programmable power supply is being commissioned that will provide flexible programming of the poloidal inductive electric field, to identify optimum inductive current-profile control for tearing suppression, longer duration, and higher plasma current. Also it will enable enhanced waveform control for oscillating-field current drive (Section II).

Two RF methods, lower-hybrid (LH) waves and electron-Bernstein waves (EBW), are being assessed for possible steady-state current-profile control, with each system capable of injecting about 200 kW RF power. Images of antennas used for LH and EBW are shown in Fig. 2. Soft and hard X-rays are observed in a region around the antenna for LH injection at 800 MHz. For EBW injection at 3.6 GHz, soft X-rays are observed and coupling to the plasma is deduced via direct probe measurement of the wave fields. Ray-tracing with the GENRAY code and Fokker-Planck modeling with the CQL3D code is being used for both RF systems to understand wave absorption and energetic electron behavior.

Figure 2: LH and EBW antennas shown before RF injection experiments.

II. Current Sustainment

Present RFPs are (formed and) sustained by toroidal induction, which is inherently transient due to poloidal flux accumulation, and which furthermore tends to drive the current profile to be more peaked, away from marginal tearing stability. Steady-state sustainment of the plasma current may be advantageous. There is only a small neoclassical, steady-state bootstrap current because the toroidal magnetic field is small. Thus another important part of RFP research is toward developing an efficient, steady-state sustainment method compatible with this configuration. Also, it is important that sustainment and improved confinement be compatible with each other.

Oscillating-field current drive (OFCD) is a candidate for efficient, steady-state RFP sustainment in which two AC electric fields, in the poloidal and toroidal directions, interact with the plasma undergoing magnetic relaxation to produce a DC toroidal plasma current. Full OFCD sustainment has been modeled using nonlinear, 3D, resistive-MHD calculations [5]. Its

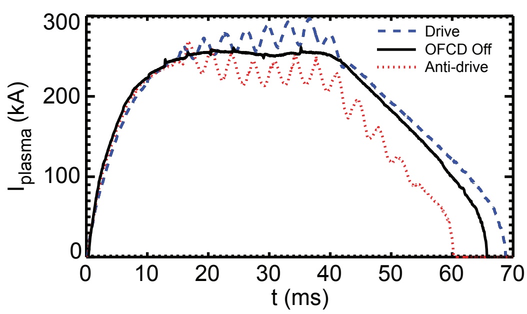

Figure 3: Plasma current versus time for a pulse with OFCD set to drive, set to anti-drive, and off.

confinement properties are unknown, but could be negatively affected by the magnetic relaxation involved. In MST OFCD has provided up to about 10% additive current, as plotted in Fig. 3, with Ohmic current-drive efficiency [6]. Energy confinement and beta are slightly increased rather than decreased.

A new, 1-MW, 25-keV, 20-ms neutral-beam injector (NBI), manufactured by the Budker Institute of Nuclear Physics, is in preparation for use in tests of on-axis current drive, plasma heating, and possibly current-profile control. It will facilitate MST investigations of the RFP beta limit, fast-ion confinement, momentum transport, and Alfven-eigenmode stability. A schematic of the NBI is shown in Fig. 4.

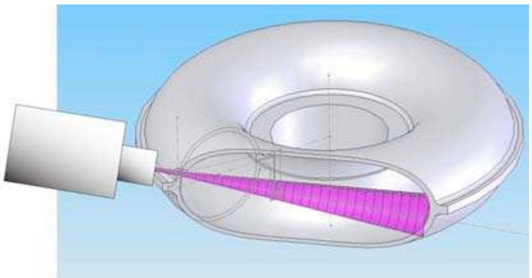

Figure 4: Schematic of NBI.

III. Summary

This paper has identified two main, interrelated challenges for RFP research: confinement and sustainment. MST projects addressing these issues, including improved confinement by inductive current-profile control, RF injection for possible steady-state profile control, partial OFCD for sustainment, and NBI for current drive and profile-control experiments, have been highlighted.

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