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Spheromak Energy Transport Studies via Neutral Beam Injection

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Disclaimer

Auspices Statement

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FY07 LDRD Final Report
Spheromak Energy Transport Studies via Neutral Beam Injection
LDRD Project Tracking Code: 06-ERD-042
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Abstract

Results from the SSPX spheromak experiment provide strong motivation to add neutral beam injection (NBI) heating. Such auxiliary heating would significantly advance the capability to study the physics of energy transport and pressure limits for the spheromak. This LDRD project develops the physics basis for using NBI to heat spheromak plasmas in SSPX. The work encompasses three activities: 1) numerical simulation to make quantitative predictions of the effect of adding beams to SSPX, 2) using the SSPX spheromak and theory/modeling to develop potential target plasmas suitable for future application of neutral beam heating, and 3) developing diagnostics to provide the measurements needed for transport calculations. These activities are reported in several publications.

Introduction/Background

The Sustained Spheromak Physics Experiment (SSPX) at Livermore (Fig. 1a) was built to examine key physics questions related to the potential of the spheromak to operate as a magnetic confinement fusion device. The primary attractive feature of the spheromak concept is that, rather than using external coils, it uses currents in the plasma itself (driven by an internal plasma dynamo) to produce the confining toroidal magnetic field. This could lead to smaller, simpler fusion power plants. At present, it is unknown if the spheromak configuration can provide sufficient energy confinement to allow the plasma to be heated to thermonuclear temperatures.

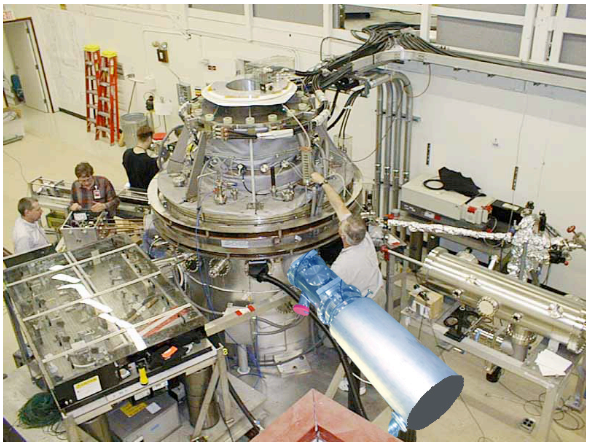

Fig. 1. Artist's conception showing a single neutral beam (blue highlight) mounted on SSPX spheromak.

Using SSPX, we are learning how to control the internal current profiles to simultaneously maximize the strength of the confining magnetic field while minimizing internal turbulence and heat loss [1,2,3,4,5,6,7,8,9]. So far, peak plasma electron temperatures reach T_e~500eV, edge magnetic fluctuations fall below 0.5%, and the electron thermal transport is in the range observed in tokamaks, levels of performance which are well beyond those achieved in earlier spheromak experiments [10]. Experimental results are well connected to recent advances in numerical simulation of SSPX [11,12,13]. This progress provides strong motivation for adding auxiliary heating. Until now, spheromak plasmas were heated solely by resistive dissipation of internal plasma current (ohmic heating). The DOE renewed funding for the SSPX project for FY06-09 at a level that supported installing 1.8MW of neutral beam heating in FY08. Two 900kW beams were scheduled to be purchased from the Budker Institute in Russia. An artist's sketch of one such beam mounted on SSPX is shown in Fig. 1. However, the SSPX program was shutdown at the end of FY07 and program funds redirected. This precluded purchase of the beams and an experimental test of neutral beam injection on SSPX.

The high performance of the SSPX experiment, combined with the expectation that NBI heating would become available on SSPX in FY08, motivated this LDRD proposal to more fully explore the physics of NBI heating in spheromaks. Because this would be the first application of NBI heating to a spheromak, significant questions arise, which we explore through a combination of simulation and experiment. For example, what plasma conditions (density, field strength, and confinement) are needed to produce good fast-ion confinement and measurable heating? What injection geometry (e.g. radial or tangential) is optimal for the spheromak? What operating scenarios yield the best target plasmas for neutral beam heating? Which beam-based diagnostics are best suited to the operating environment to study beam-heated spheromak plasmas?

This project represents a significant step forward for spheromak research on several levels. First, we are extending the use of a fully benchmarked 2d MHD/transport code developed for tokamaks, the CORSICA code [14], to study beam heating and fast-ion orbit effects on a self-organized magnetic configuration. Second, in developing target plasmas for NBI heating, we are learning how to better control the internal current profile and magnetic fluctuations using a variable-current programmable capacitor bank. Third, the availability of neutral beams provides unique diagnostic capabilities such as charge exchange recombination spectroscopy. Finally, the expectation that NBI heating will provide a controllable increase in plasma temperature is providing impetus to discover the pressure limit in the spheromak configuration. The ratio of the plasma pressure to the magnetic field pressure ($\beta=2\mu_o nkT/B^2$) is an important measure of the efficiency of a magnetic fusion power plant, and every magnetic field configuration has a maximum β for which the plasma maintains MHD stability. Auxiliary heating would provide a clean experimental test for the first time in a spheromak.

Results/Technical Outcome

Detailed results on are reported in a series of technical reports, journal articles, and conference reports as outlined below. They are organized by the three major activities of 1) numerical simulation to make quantitative predictions of the effect of adding beams to SSPX, 2) using the SSPX spheromak and theory/modeling to develop potential target plasmas suitable for future application of neutral beam heating, and 3) developing diagnostics to provide the measurements needed for transport calculations.

Numerical Simulations of Neutral Beam Heating and Current Drive

1. **UCRL-JRNL-237238**, R. Jayakumar, L.D. Pearlstein, T.A. Casper, T.K. Fowler, D.N. Hill, B. Hudson, H.S. McLean, J. Moller, "Studies on Neutral Beam Injection into the SSPX Spheromak Plasma," Submitted to Nuclear Fusion February 2008.
2. **UCRL-TR-235704**, R. Jayakumar, L.D. Pearlstein, T.A. Casper, T.K. Fowler, D.N. Hill, B. Hudson, H.S. McLean, J. Moller, "Studies on Neutral Beam Injection into the SSPX Spheromak Plasma," October, 2007.
3. **UCRL-CONF-222188**, L. D. Pearlstein, T. A. Casper, D. N. Hill, L. L. LoDestro, H. S. McLean, "Calculation of Neutral Beam Injection into SSPX," June 2006.

Development of Target Plasmas (Experiment +Theory/Modeling)

4. **UCRL-CONF-225553**, D. N. Hill, H. S. Mclean, R.D. Wood, T.A. Casper, B.I. Cohen, E. B. Hooper, L. L. LoDestro, L. D. Pearlstein, C. Romero-Talamás, "Confinement Studies in High Temperature Spheromak Plasmas," October, 2006.
5. **LLNL-JRNL-401131**, T. K. Fowler, R. Jayakumar, H.S. McLean, "Stable Spheromak Equilibria with Zero Edge Current," Submitted to Physical Review Letters Feb. 2008.
6. **LLNL-TR-400902**, T. K. Fowler, R. Jayakumar, "Stable Spheromaks with Profile Control," Jan. 2008.
7. **UCRL-TR-229698,** T. K. Fowler, "Stabilized Spheromak Fusion Reactors," April 2007.
8. **LLNL-JRNL-401290**, B. Hudson, H.S. McLean, R. D. Wood, E.B. Hooper, D.N. Hill, J. Jayakumar, J. Moller, C. Romero-Talamás, T.A. Casper, J.A. Johnson III, L.L. LoDestro, E. Mezonlin, L.D. Pearlstein, "Energy confinement and magnetic field generation in the SSPX spheromak" to be published in Phys. Plasmas 2008.

Development of Diagnostics

9. **LLNL-JRNL-400016**, J. D. King, H. S. McLean, R. D. Wood, C. A. Romero-Talamás, J. M. Moller, "A Passive Ion Doppler Spectrometer Instrument for Ion Temperature and Flow Measurements on SSPX," submitted to Review of Scientific Instruments Dec. 2007.
10. **UCRL-POST-236272**, J.D. King, H.S. McLean, E.C. Morse, R.D. Wood and the SSPX Team, "Ion Doppler Spectroscopy Measurements on SSPX," Nov. 2007.
11. **UCRL-POST-236364**, D. Montez, B. Hudson, D. Correll, H.S. McLean, "Correlation of Soft X-ray Emission with Thomson Scattering Measurements of Electron Temperature in SSPX," Nov. 2007.
12. **UCRL-TR-223809**, A. R. Ludington, D. N. Hill, H. S. McLean, J. Moller, R. D. Wood, "Time-resolved Temperature Measurements in SSPX," August 2006.

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