*"Formation and Sustainment of a
Very Low Aspect Ratio Tokamak
Using Coaxial Helicity Injection"*

FINAL REPORT

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1 Executive Summary

During the reporting period of this HIT grant (1 June 1995 – 31 May 1997) we've conducted further stability analysis, used the TIP diagnostic to measure plasma fields in HIT, and developed a single-parameter helicity injector model.

1.1 HIT Results and Analysis

From PEST stability analysis, a mode has been found that could explain the $n = 1$ mode observed during high temperature and high current operation of the HIT experiment. EFIT in conjunction with surface probe and paramagnetic flux data are used to find the equilibrium. The equilibrium is converted to flux coordinates by J Solver and then analyzed for stability in PEST. The calculated mode occurs when the equilibrium has a local maximum in q near the separatrix. The instability couples to the mode resonant flux surfaces (with $q = 11$) on both sides of the peak in q . This mode is probably playing a role in the relaxation that drives current on the closed flux. The stability analysis to date has been ideal MHD, however, the mode structure is similar to that of a double tearing mode which is probably also unstable. It may be difficult to distinguish ideal and resistive modes from the data and it seems likely that if this ideal mode is unstable, the double tearing mode is also unstable and involved in the relaxation that gives the current drive.

The Transient Internal Probe (TIP) diagnostic has been developed to measure the internal magnetic fields. The time that a magnetic probe can be in the plasma is limited due to probe surface heating, leading to ablation. The TIP is shot through the plasma with a two stage light gas gun at a velocity of 2 km/s. A scan to the magnetic axis is done in 100 ms while the total time in the plasma is 500 ms. The probe (10mm x 4mm x 4mm) is made of high-verdet-constant glass. The local magnetic field is determined by measuring the Faraday rotation of a polarized laser beam aligned with the probe trajectory. These first experiments have successfully measured the toroidal magnetic field at about 4 ms into the discharge. The present sensitivity is 40 G while the paramagnetic change in the toroidal magnetic field is estimated to be about 100 G. The internal structure of the $n = 1$ mode is observed to have large amplitude only for the edge 0.1 m in agreement with the PEST results.

A new model for the injector operation which assumes a uniform resistiv-

ity does surprisingly well in accounting for the edge magnetic field produced in cold, low current discharges. Cold low current discharges, believed to have small amounts of closed flux are ideal for studying the open field line and injector physics. The model simply solves for the force-free equilibrium on the open field lines using a uniform resistivity as the only fitting parameter. Good agreement with the measured surface poloidal fields and the measured injector current is achieved. The measured injector voltage is an input parameter. This model is now being incorporated into the EFIT code for analysis of hotter higher current conditions where large amounts of closed flux are produced.

Computational support for the HIT project has been progressing on several fronts in time-dependent two- and three-dimensional modeling. With the parallelization effort of the MACH3 code largely completed, three-dimensional simulations of HIT have been successfully accomplished. An input reader was written that accepts equilibria generated from EFIT as an initial condition for the time-dependent simulation. The other effort underway is to write an implicit algorithm for MACH3 that will allow computational time steps of arbitrary size. The implicit algorithm is an approximate Riemann solver which will accurately capture the discontinuity in the magnetic field in the thin layer between the closed and open flux.

1.2 HIT-II Upgrade Design

HIT has undergone a significant upgrade to the "HIT-II" configuration. HIT-II maintains the present plasma shape while replacing the thick copper flux conserver with a thin stainless-steel shell. Equilibrium fields are provided by a set of feedback-controlled coils, (acting like a 'power-crowbarred flux conserver'). The poloidal field coil (PFC) set allows transformer capability, providing additional ohmic heating, and allowing comparison of transformer current drive confinement with CHI current drive confinement, as well as current profile control. Prototype feedback power supplies have been tested at 900 V and 1000 A, and the 17-20 production models are being constructed. Parts for HIT-II has been designed, ordered, and been received under this grant, and are being assembled under the subsequent grant.

1.3 HIT Program Collaborations

The HIT program is fortunate to participate in a collaborative effort with the National Spherical Tokamak Experiment (NSTX) at the Princeton Plasma Physics Laboratory (PPPL), General Atomics (GA) of San Diego, CA, the Himeji Institute of Technology in Japan, the University of Manchester Institute of Science and Technology (UMIST), and Sterling Scientific Incorporated (SSI) of Madison WI.

2 Program Plan

The Program Plan is progressing as scheduled in the proposal for this grant period. The goals for this grant period are:

- Study and optimize coaxial helicity injection (CHI) as a method of tokamak current drive.
- Measure and optimize the core confinement of a low aspect ratio tokamak formed and sustained by CHI.
- Measure the confinement of a low aspect ratio tokamak formed by CHI and sustained with an ohmic transformer (OH).
- Study the core confinement as a function of the current profile of a low aspect ratio tokamak.