Progress and Plans for the HIT-SI Experiment

P. E. Sieck, P. Gu, W. T. Hamp, V. A. Izzo,
T. R. Jarboe, B. A. Nelson, A. J. Redd, J. A. Rogers,
U. Shumlak

University of Washington

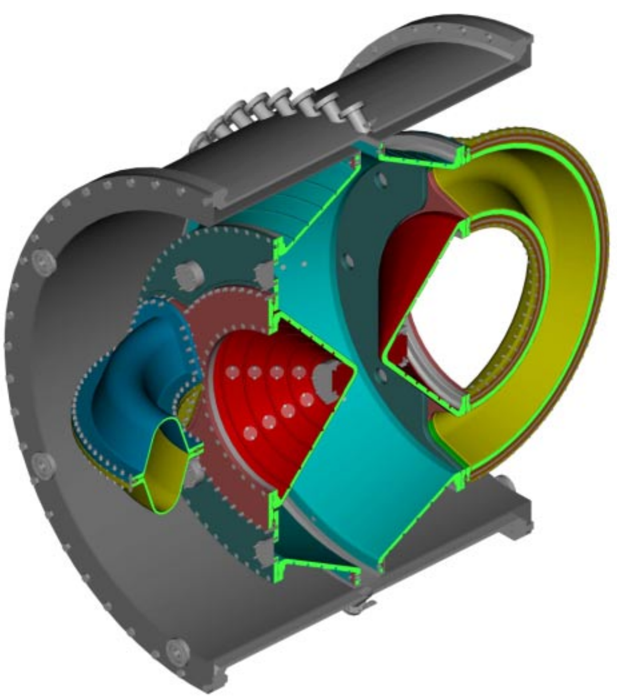
Abstract

The next step in the Helicity Injected Torus (HIT) program is HIT-SI, a “bow tie” spheromak to be formed and sustained by Steady Inductive Helicity Injection (SIHI). SIHI injects helicity at a nearly constant rate with no open field lines intersecting the boundary.[1] HIT-SI has been designed with a bow tie geometry to achieve stable high-beta (>10%) spheromak equilibria.[2] Injector dynamics depend greatly on reconnection rates in two locations: deep in the injector, and at the edge of the spheromak equilibrium. The first stage of HIT-SI operation concentrates on formation of a spheromak and sustainment for 1 ms, where the injector dynamics can be studied and the formation parameter space can be explored. Once these goals are met, the experiment will move into the second stage of operation, where the discharge duration will be extended and the device will inherit a suite of diagnostics from the existing HIT-II device.

[1] T. R. Jarboe, Fusion Technology **36** (1), p. 85, 1999
[2] U. Shumlak and T. R. Jarboe, Phys. Plasmas **7** (7), p. 2959, 2000

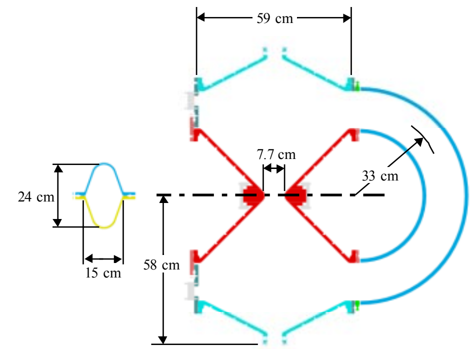
Introduction

The Helicity Injected Torus with Steady Inductive Helicity Injection (HIT-SI) is a new spheromak under construction at the University of Washington. HIT-SI has several unique features, the most notable being the “bow tie” cross-section of the confinement region and the presence of two semi-toroidal helicity injectors at each end.

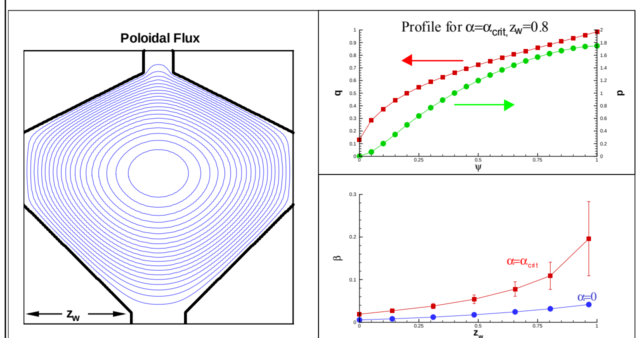


A “cutaway” view of the HIT-SI device, with the cross-section highlighted in green.

HIT-SI Dimensions



Bow tie geometry and edge drive improve shear, <β>



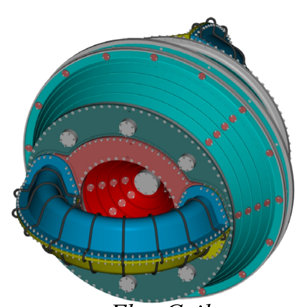
From Ref. 2

Calculations have predicted that the bow tie geometry provides a higher Mercier β limit. HIT-SI is well poised to take advantage of the bow tie geometry, as SIHI does not produce large voltages across the shortened axis. Furthermore, edge current drive raises the edge $\lambda=\mu_0 j/B$ beyond the minimum energy state (λ=const). The λ profile is approximated as linear in ψ, with $d\lambda/d\psi=2\alpha\bar{\lambda}$ and $\bar{\lambda}=\lambda(\psi=0.5)$. The edge is driven until α approaches α_{crit}, where the n=1 mode becomes only marginally stable and relaxation activity begins to flatten the current profile. At this point, the edge shear is greatest and the highest $\langle\beta\rangle$ can be attained.

Coils on HIT-SI

Two coil sets are required for each helicity injector on HIT-SI. The “voltage” circuit provides the loop voltage on the injector by using the injector plasma as the secondary of an air-core transformer, with an adjustable number of turns on the primary coil. The “flux” circuit provides the injector flux that interacts with the spheromak equilibrium. These coils are shown individually below, with the outer tank removed for clarity.

Voltage Coil

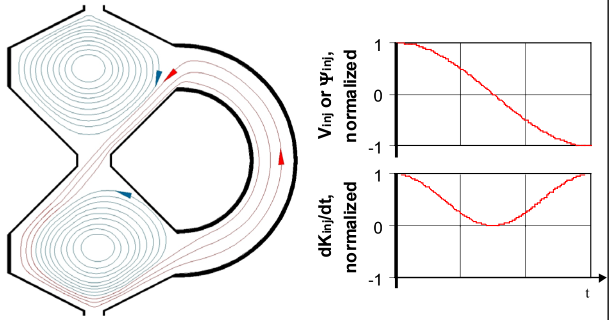


Flux Coil

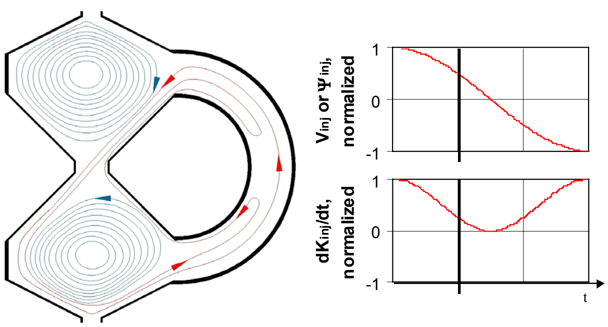
Steady Inductive Helicity Injection (SIHI)

SIHI is performed by oscillating the voltage circuit and the flux circuit on a single injector, such that the flux and loop voltage vary sinusoidally and in phase. The helicity injection rate is $\dot{K}=2V_{inj}\Psi_{inj}$. By oscillating the second injector 90° out of phase from the first, a constant helicity injection rate is achieved.

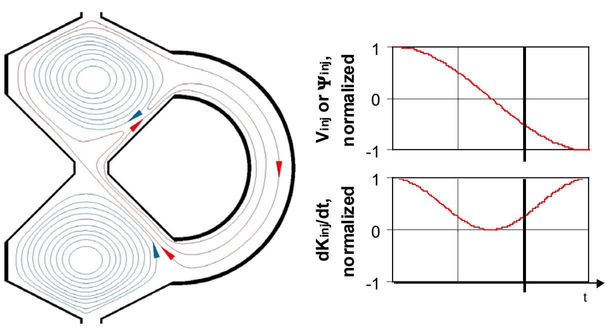
If the injector oscillation period is much longer than the reconnection time with the spheromak, then the injector flux is expected to completely link the equilibrium, as shown below.



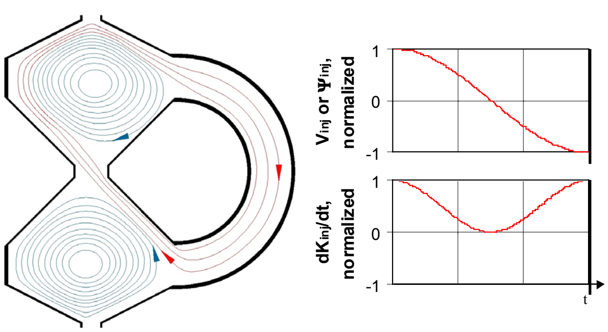
The start of the cycle: the injector plasma is driven like an RFP, with the reversal surface very near the wall ("spheromak" mode).



As the cycle continues, the injector flux is reduced by introducing fields of the opposite direction. The edge fields reconnect and move to the spheromak equilibrium.

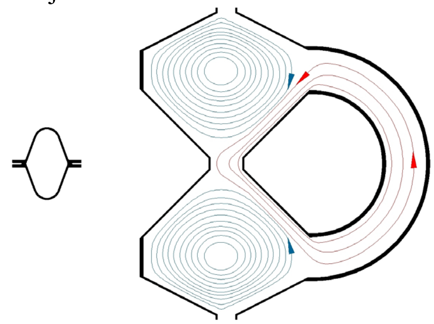


Once the injector flux changes sign, the injector operates as a stabilized pinch. The injector flux begins to link with the spheromak equilibrium.



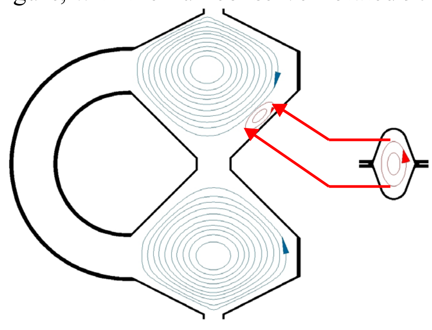
The half-cycle is complete.

If the injector oscillation period is much shorter than the reconnection time with the spheromak, then the injector flux is expected to form a ring that merges with the equilibrium on its own time scale, as shown below. In the following figures, the injector on the left side has been neglected, as it is not expected to interact with the right-side injector in this model.



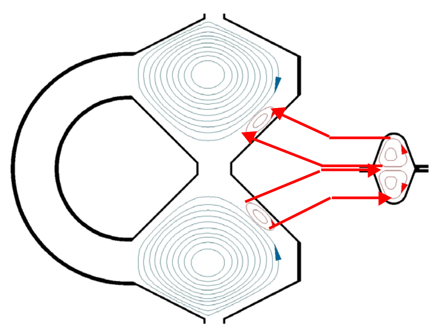
At the start of the cycle, the injector flux and voltage are at maximum. The injector flux passes through the confinement region without linking the equilibrium.

The next figure shows the same instant in time as the above figure, with the flux conserver rotated 90°.

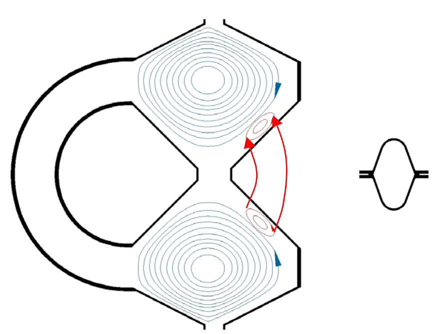


The injector flux tube kinks to one side of the equilibrium.

The injector cycle has been designed so that the Poynting flux is always into the plasma, so that the net injector flux is reduced by introducing oppositely-directed fields.

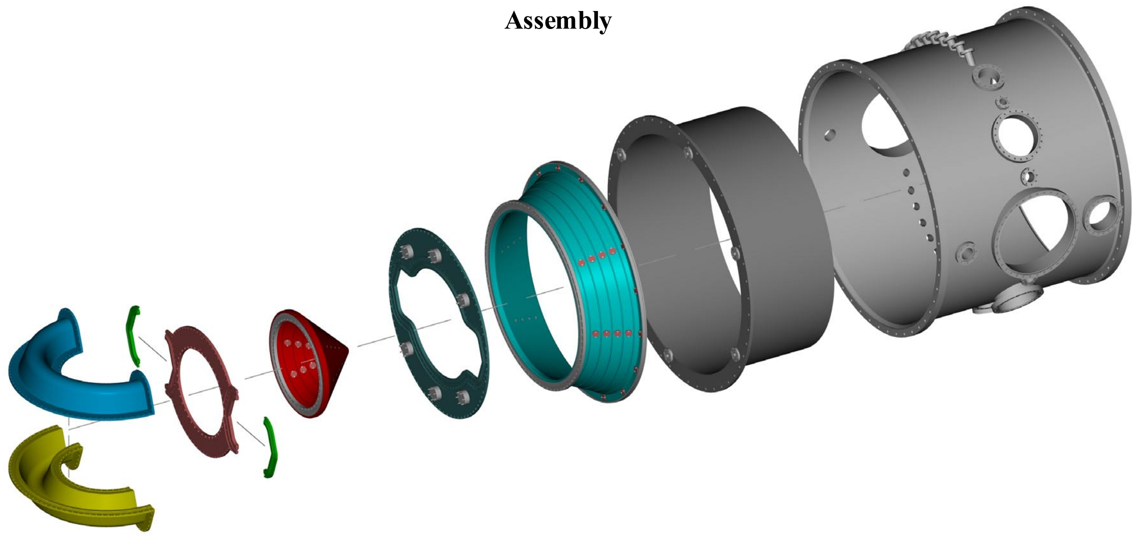


The new flux is depicted as a separate flux tube.



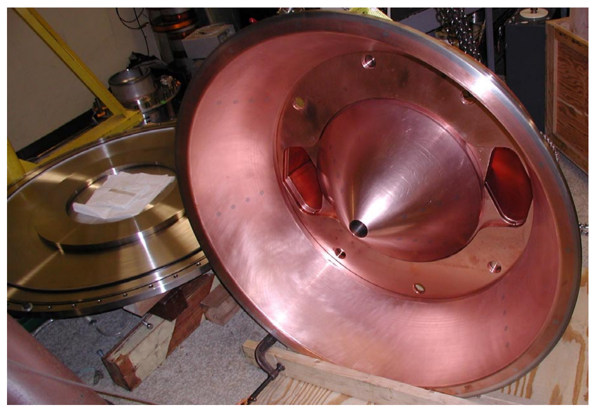
The opposing fields are expected to reconnect in the injector, forming a ring that merges with the spheromak.

Assembly



Construction Progress

Forging, brazing, and machining operations are complete. A test assembly has verified the fit of all major components.



The assembled half-shells successfully held vacuum, with no detectable leaks through the brazed joints.

The multiply-connected double o-ring system also sealed without detectable leaks when vulcanized Viton was used to join the sections of o-ring material. It was found that joints made with Super Glue did not seal adequately, nor did the Super Glue hold at temperatures above 150°C.

Remaining Construction Tasks and Starting Operations

The final off-site construction task remaining is the application of the plasma-sprayed alumina ceramic coating to the plasma-facing surfaces of the device. Once this is complete, the large cones will be welded to the stainless steel cylinders, then installation and calibration of the surface magnetic probes will commence.

The first stage of HIT-SI operation will demonstrate formation of a spheromak and sustainment at 5 kHz for 1 ms (5 injector cycles). This will be performed while HIT-II continues operations. Once some experience has been gained in operating HIT-SI, it will be moved into the current HIT-II tank and inherit the HIT-II diagnostics. For more information on HIT-SI and HIT-II diagnostics, please see R. J. Smith's poster in this session (KP1.086).

Summary

HIT-SI is a bow tie spheromak under construction at the University of Washington. The bow tie geometry and edge drive will allow HIT-SI to achieve stable spheromak equilibria with high β, possibly greater than 10%. HIT-SI implements SIHI, an inductive helicity injection technique that provides formation and steady-state edge drive of the spheromak without open field lines. The interaction mechanism of the injector flux with the spheromak equilibrium will be highly dependent on the injector oscillation frequency and the plasma reconnection rates.

Construction of the HIT-SI device is nearly complete. The plasma-facing surfaces are currently being coated with plasma-sprayed alumina ceramic. Once this coating has been applied, the components will be assembled and the installation and calibration of the magnetic diagnostics will begin.