Helicity Injected Torus (HIT) Current Drive Program

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1. Executive Summary

The HIT program studies and develops helicity injection current drive for future magnetic confinement burning plasma experiments. In a reactor, helicity injection current drive promises to be orders of magnitude more efficient than neutral beam or RF current drive. Providing efficient steady state current drive is one of the critical outstanding issues for the next generation of long pulse tokamaks. It is also essential for spheromaks and reversed-field pinches (RFPs), which have lower β-poloidal (requiring more current) and lower q (giving less bootstrap current). Presently, work is on an innovative new approach to helicity injection current drive, the steady inductive helicity injection (SIHI) current drive method for forming and sustaining high-β spheromaks, spherical tori (STs), tokamaks, and RFPs. In SIHI, two or more inductive injectors, oscillating out of phase, produce a constant helicity injection rate for a constant, optimized current profile. The SIHI front-end was installed on the established HIT facility at the University of Washington, forming the <u>H</u>elicity <u>I</u>njected <u>T</u>orus with <u>S</u>teady <u>I</u>nductive helicity injection (HIT-SI) experiment. In this three year grant cycle the experiment has achieved the record current gain for spheromaks of greater than 3.5, toroidal currents of up to 90 kA and separatrix currents of 60 kA and ran at injector frequencies of 5.8, 14.5, 36.8, 53.5, and 68.5 kHz. Careful validation studies using NIMROD have shown that two-fluid pressureless MHD agree with current gain and fluctuation amplitude only at low frequency and the profile differs from the experiments. The simulation is kink unstable while the experiment is kink stable.

We discovered that only high edge current and magnetic fluctuations across the mean field equilibrium (and not instability or relaxation) are required for dynamo current drive. By imposing fluctuations HIT-SI is the first experiment to meet both of these requirements on a stable equilibrium and is the first experiment to sustain a kink-<u>stable</u> equilibrium with dynamo current drive. All previous dynamo current drive experiments produced the fluctuations through instability. A NIMROD simulation of a scaled-up HIT-SI geometry shows that when fluctuations are applied to a stable equilibrium, closed flux is preserved and destroyed only by instability. Thus the proper causal relations from the observation that poor confinement is correlated with fluctuations are that instability causes fluctuations and instability causes poor confinement **not** that fluctuations cause poor confinement. Thus for dynamo current drive to be compatible with good confinement the fluctuations must be imposed on a stable equilibrium, giving Imposed Dynamo Current Drive (IDCD). Even more exciting, as the frequency was increased the equilibrium transitioned from low-beta to high-beta and a more symmetric equilibrium. The frequency of the transition indicates that the imposed fluctuations are controlling the pressure driven modes. In addition, dynamo current drive should cause differential rotation, the key ingredient for transport barriers.

This program is for the validation of extended MHD simulations using PSI-TET and NIMROD working with the Plasma Science and Innovation Center (PSI-Center), the continual development and understanding of IDCD, the demonstration and study of profile control, and the study the rotation profile of IDCD with and without rotating fluctuations. The new HIT-SI3 configuration has three new smaller injectors, all mounted on the same end of the spheromak. The relative phasing of the injectors controls the imposed fluctuation profile and allows rotating fluctuations to be imposed. HIT is particularly attractive for this research because the inductive drive removes the electrode-plasma interface, which is difficult to model.

2. Program objectives

This white paper is about the HIT program. A new energy efficient current drive and profile control method, recently discovered by the HIT program, called Imposed Dynamo Current Drive[1] (IDCD) is being developed. A kink-stable equilibrium can be efficiently sustained using imposed fluctuations, and the current profile can, in principle, be controlled for optimum confinement by controlling the imposed fluctuation profile. Both are large steps for controlled fusion. In particular, experiments using three injectors on one side (HIT-SI3) will be done. a) With 120^{o} phasing, the effects of imposed fluctuations on plasma rotation and stability will be studied. b) Profile control by changing the imposed fluctuation profile, which depends on injector phasing, will be investigated. c) Improved density control may allow the pulse length to be increased from 1 ms to 6 ms, making it possible to heat to 100 eV. d) The edge of the equilibrium will be studied. e) Codes for predicting the current profiles especially in the edge will be validated and more generally the HIT team will work with the PSI-Center to develop validated codes for predicting the behavior of future confinement experiments using IDCD. The current drive method is being applied to a high-β spheromak and has applications to reversed-field pinches, tokamaks, and spherical tori.

3. Background and Accomplishments

3.1. Motivation

The Helicity Injected Torus (HIT) program studies and develops helicity injection current drive for magnetic confinement. With the achievement of greatly improved parameters on the Helicity Injected Torus with Steady Inductive helicity injection (HIT-SI) experiment, during the present grant period, came the discovery of Imposed Dynamo Current Drive[1] (IDCD), a method of efficiently sustaining a kink-stable equilibrium with the possibility of current profile control. Toroidal currents up to 90 kA and over 3.5 times the injector current (the spheromak record) and separatrix current of 60 kA are achieved using IDCD on HIT-SI[2]. In addition, at high frequency ($\omega_{inj} \geq v_i/a$ where v_i is the ion thermal speed and a is the minor radius) high-β equilibria are sustained, another first for spheromaks[3]. Kink-instability driven relaxation was considered a necessary part of dynamo current drive until now. With IDCD, the fluctuations are imposed on a stable plasma configuration using asymmetric injectors resulting in sustainment that is compatible with closed flux. NIMROD simulations show that stable equilibria can have closed flux with imposed δB/B of 10%. The high power efficiency with low-cost power of inductive injectors removes the requirement of high bootstrap fraction and lower current-drive costs to an attractive level. Efficient sustainment with good confinement enables the spheromak and RFP as reactor concepts.

Current drive by conventional means (e.g. neutral beam injection, lower hybrid waves) suffers from intrinsically low efficiency. In particular, for current driven in reactor conditions, the power coupled to the plasma through these methods needs to be as much as 1000 times greater than the minimum power to sustain the driven current against Ohmic dissipation[4,5], that is $P_{Ohm} / P_{CD} = 10^{-3}$. There is also an efficiency penalty for generating the power and delivering it to the plasma of $\eta_{CD} \sim 0.25$ with present technology[6]. These considerations lead to an unacceptably high recirculating power fraction $f_{REC,}$ as high as 0.5 for a DEMO-type reactor[7], which would likely preclude commercial acceptance. There is consensus, therefore, in the fusion research community (e.g. Theme 2 and Thrusts 4-5 of the ReNeW planning workshop) that significant advances in current drive must occur in order to make fusion economically viable. In the mainstream of fusion development, as reflected in the ITER Physics Basis[8], such advances are envisioned to come from a combination of technology improvement (raising the power coupling efficiency to 0.6-0.7) and reliance on a very high fraction of bootstrap current—however, even if these improvements are attained to the most optimistic degree, they are foreseen to improve f_{REC} only to marginally acceptable levels for commercialization. In addition, profile control will be difficult with a small fraction of the current being driven.

In contrast, relatively little attention is given to the high ceiling for improvement in the parameter P_{Ohm} / P_{CD}. Helicity injection current drive, the research topic of this white paper, has a predicted P_{Ohm} / P_{CD} of the order 0.1 for reactor conditions[9]—if developed, this two order of magnitude improvement over conventional methods could reduce the dominance of current drive cost in a reactor to insignificance. This could allow the mainline of fusion development, the tokamak, to be economically viable. If, however, the tokamak does not gain commercial acceptance, then helicity injection current drive could be all the more important to enable alternative magnetic confinement concepts that depend even more fundamentally on large amounts of efficient, externally driven current, such as spheromaks and reversed field pinches (RFPs). The HIT program was motivated by the success of Coaxial Helicity Injection (CHI) current drive on spheromaks[10] and by helicity injection current drive on RFPs[11] and tokamaks.[12] CHI start-up was investigated in the HIT-II experiment and then successfully scaled up to NSTX[13]; this is an important precedent for the ability of the university-level HIT program to produce innovative techniques that scale to national-level fusion facilities. This research is to further develop and study IDCD to form and sustain tokamaks, spherical tori (ST), spheromaks, and RFPs.

This research also contributes to the goal of reducing operational and maintenance complexity of toroidal confinement and Thrust 18 of the ReNeW planning workshop: "Achieve high-performance toroidal confinement using minimal externally applied magnetic field". Presently, the tokamak has three coil sets and a toroidal vacuum chamber that are interlinked. The coil sets are the transformer solenoid, the toroidal field coils and the equilibrium coils. The transformer is used for current drive on present tokamaks and works very well since the plasma current is almost purely toroidal. However, since it is only used for startup in a reactor and other current drive methods must be developed anyway, it can be eliminated and indeed recent ARIES reactor studies[14] do not have this coil. The solenoid-free startup method developed on HIT-II using CHI that has been very successful on NSTX[13] and the first DEMO will probably not have the transformer coil set. Of the remaining two coils only the equilibrium coils are fundamental for toroidal confinement and stable equilibria have been produced transiently that have good confinement at temperatures in the kilovolt range using very little[15] or no[16,17,18,19,20,21] externally produced toroidal field. With IDCD, efficient steady-state current drive with sufficient current profile control is possible and elimination of the toroidal field coil allows a simple vacuum vessel, further reducing operational and maintenance complexity leading to economically competitive fusion power.[22]

In addition to current drive, the program focuses on rotation generation, profile control, and code validation as described in Section 4. This program contributes to the FES mission because understanding and developing efficient current drive is helping "to build the scientific foundation needed to develop a fusion energy source" and validation work is helping with "creating theoretical and computational models to resolve essential physics principles." This program contributes to FES goals 1 and 4. This program is contributing to the *2007 Greenwald's FESAC panel report on Priorities, Gaps, and Opportunities* through Theme A6 "Plasma Modification by Auxiliary Systems" and A3 "Validated Theory and Predictive Modeling" and Gap G-4. "Control strategies for high-performance burning plasmas, running near operating limits, with auxiliary systems providing only a small fraction of the heating power and current drive". With IDCD, all the current can be driven without the need of bootstrap current because IDCD is orders of magnitude more efficient. IDCD also contributes through recommendation 4 I-2. "Extensions to ITER AT capabilities". This research applies to all five top tier thrusts identified by the FESAC priorities panel.[23] Other issues addressed include: reducing operational and maintenance complexity of toroidal confinement, and some plasma facing materials development. This paragraph applies to our initiative white paper as well.

3.2. Steady Inductive Helicity Injection (SIHI) current drive

SIHI has constant inductive helicity injection with no power or helicity ejection. . HIT-SI uses a bow-tie cross-section flux conserver to produce a high-β spheromak.[24] For inductive drive, the time-averaged voltage on one injector is zero with the voltage passing through zero. Thus, for constant injection, at least two injectors must be used so one can inject during the zero crossing of the other. To prevent helicity ejection when the voltage is negative, the flux must change sign with the voltage. HIT-SI is among the simplest experiments that can meet these requirements and be compatible with the bow tie spheromak. HIT-SI has two oscillating injectors driven 90° out of phase.[25] The injectors are 180° segments of a toroidal pinch attached to a slotted flux conserver as shown in Figure 1. The individual injectors are referred to as the "X injector" and the "Y injector".

3.3. Imposed dynamo current drive

There are two requirements for imposed dynamo current drive. Externally driven edge electron current must have flow speeds higher than in the dynamo driven region (injecting helicity with $\lambda_{inj} > \lambda_{sph}$) and fluctuations must be imposed across the entire cross section that are strong enough to drive the stable current profile.[1] Figure 1 shows HIT-SI the first experiment to meet these requirements.

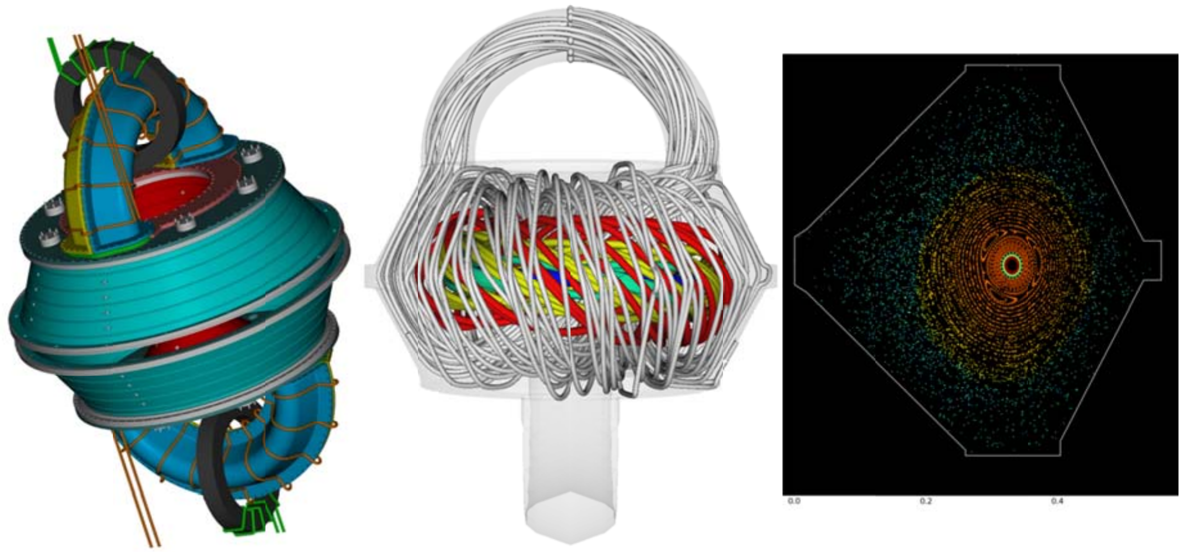


Figure 1. Left is a drawing of the HIT-SI front-end. Middle are the fields of a Taylor state equilibrium in HIT-SI. And right is a puncture plot of that equilibrium.

The middle frame of Figure 1 shows how the driven fields connect to and drive high currents in the edge. Because the injectors have *n=1* symmetry they also impose the fluctuations required, eliminating the need for instability. The right frame shows closed flux surfaces of the *n=1* distorted equilibrium. Results from a NIMROD calculation of a plasma 2.5 times the size of HIT and 30 times better conductivity are shown in Figure 2. This simulation shows that the proper causal interpretation of the observed correlation of poor confinement with fluctuations is that instability causes fluctuations and instability causes poor confinement, but fluctuations on a stable equilibrium allow the closed flux needed for good confinement. This calculation shows that the volume of closed flux grows when the equilibrium is stable and dissipates when it is unstable all with $\delta B/B$ of 10%.

Dynamo current drive can be understood based on well-known concepts: a) electron fluid is frozen to magnetic fields; b) magnetic fluctuations can be considered separately from equilibrium (mean dynamo theory); and c) field lines have tension. Figure 3 illustrates how differential electron flow distorts fluctuations so that their field line tension puts a drag on the externally-driven mean-field electron flow (red) and a drive on the dynamo-driven mean-field electron flow (blue). The toroidal current versus time, the injector impedance scaling with *j/n* of the spheromak, and the current profile data validate the model.[1] Figure 4, Figure 5, and Figure 6 show this very good agreement. For Figure 4, one calibration factor was used and it is the same value for the four conditions. For Figure 6, the injector current and flux, and the toroidal current are used but there is no calibration factor for the IDCD case. For the NIMROD and Taylor cases, the fields are normalized so the toroidal currents are the same as the experiment. Note that the magnetic axis is shifted inward for the NIMROD case due to the more hollow current profile which also gives a higher q on the magnetic axis. Also the magnetic field profile from NIMROD is flatter, than the data and IDCD, as it approaches the magnetic axis.

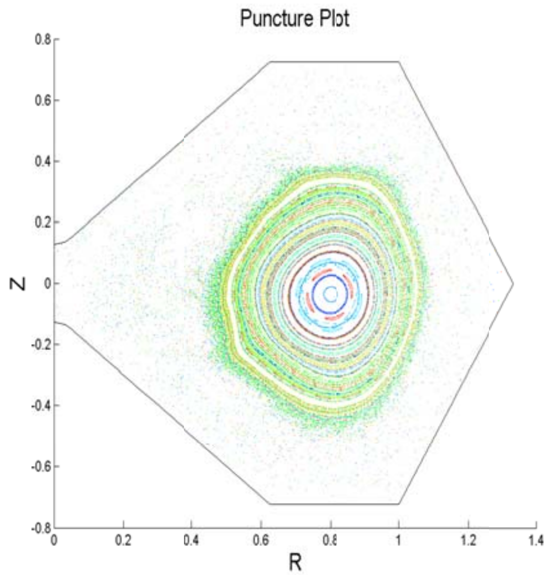


Figure 2. NIMROD simulation with current gain 9 showing closed flux in a stable equilibrium with large ($\delta B/B = 10\%$) imposed fluctuations. A reactor will have gain of ≈ 1000.

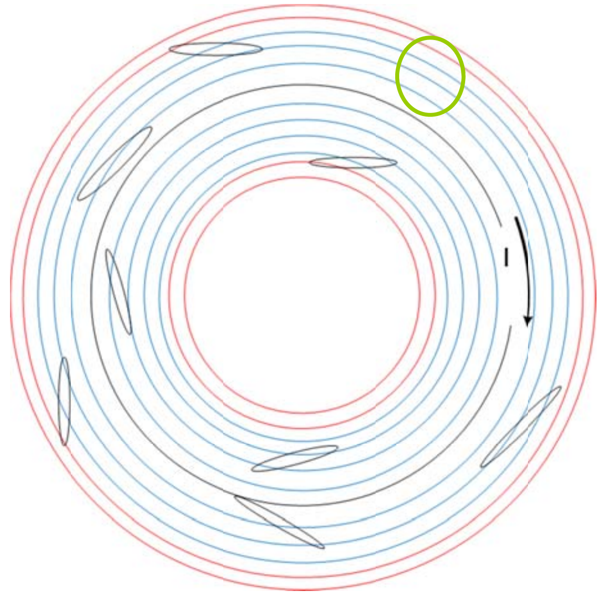
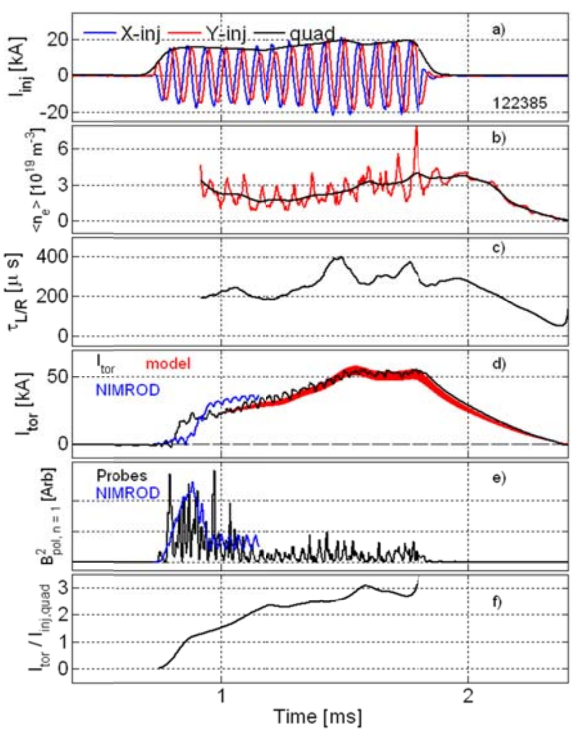


Figure 3. Idealized picture of dynamo current drive. Red lines represent the externally driven mean fields. The blue lines represent the dynamo driven field lines. The black represents fluctuations that have been distorted by sheared electron flow to become current driving. The green represents an undistorted fluctuation.



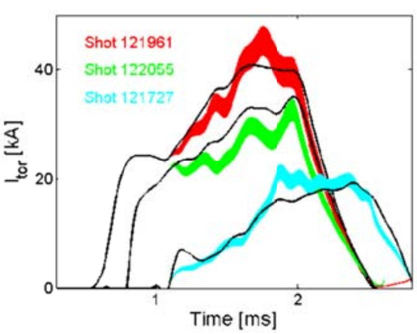


Figure 4. Left: From top to bottom I_{xinj}, I_{yinj}, and I_{inj} ; spheromak density both smoothed (black) and unfiltered (red); $\tau_{L/R}$; the spheromak toroidal current I_{tor}; amplitude of the *n=1* present; and current amplification. For I_{tor}, the black trace is the measured current and the red trace is the current predicted by the IDCD model, where the width of the red trace represents the uncertainty in the prediction. Blue trace is a two-fluid MHD simulation result. Right: Toroidal current versus time for three discharges (black) and that predicted by IDCD (colors), where the width of the trace represents the uncertainty in the prediction.

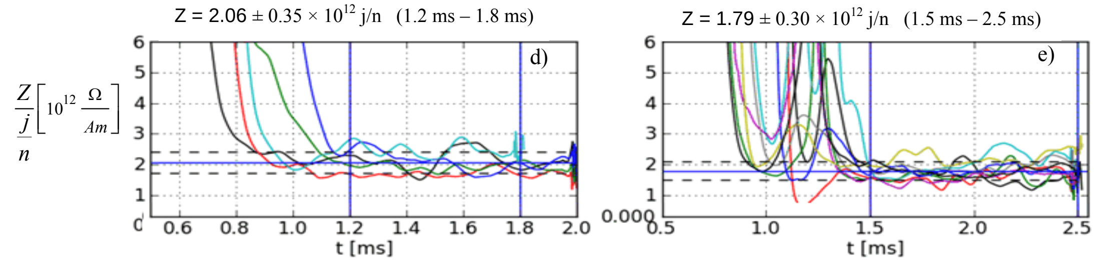


Figure 5. The real part of the injector impedance due to the spheromak region divided by *j/n*, predicted to be constant between the vertical lines when IDCD is operating.

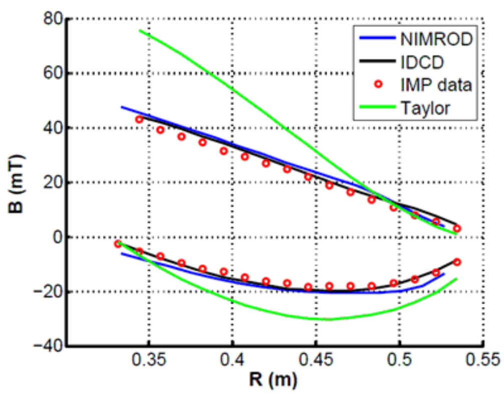


Figure 6. The black curve is the magnetic field profile of the IDCD predicted mean Grad-Shafranov equilibrium. The red dots are internal probe data with the upper toroidal field and the lower poloidal field. The green curves are the profiles for the constant λ Taylor state with I_{tor} measured and the blue curve is resistive two-fluid MHD scaled to have the measured I_{tor}. All are for shot 122385 at 1.5 ms.

Figure 7 shows the data from a high current 14.5 kHz and a high current gain 68.5 kHz discharge. The discharge time is limited because of overheating of the wall and excess density late in time. None-the-less, the pulse lengths are much longer than an injector period showing that the method is steady state.

HIT-SI has run at 5.8 kHz, 14.5 kHz, 36.8 kHz, 53.5 kHz, and 68.5 kHz. All data at gains greater than 2.5 fit very well to the two-step λ ($\equiv\mu_o j/B$) profile defined in reference 1, which is a flat, kink-stable profile. For this discussion a "kink" is a long wavelength current driven instability. IDCD seems to be causing the current penetration because: a) all fits to the data require this extremely flat j/B profile of IDCD; b) profiles are too n=1 kink-stable to be caused by kink modes; c) pressureless 2-fluid simulation show an extremely hollow profile that is unstable to n=1 kink modes confirming that the flat profiles in the experiment are not caused by kink modes. Pressure driven modes can lower the q-profile (q is the safety factor) giving current penetration and their role in relaxation is under investigation[3]. In addition, at higher frequencies the imposed fluctuations appear to control the pressure driven modes because: a) as the injector frequency is raised a transition occurs near $\omega_{inj} \approx \gamma$ (where $\gamma = v_i$/size, the growth rate of the pressure driven mode); b) the high frequency equilibria are more quiescent with much higher beta and showing sufficient confinement as in Figure 8; and c) at high frequency $\delta n/\langle n\rangle \propto \tau_{inj}$ indicating the pacing of the pressure driven mode and the slope of $\delta n/\langle n\rangle$ vs τ_{inj} agrees with measured τ_K. ($\delta n/\langle n\rangle \approx \delta p/\langle p\rangle \approx \delta W_{plas}/\langle W_{plas}\rangle \approx \tau_{inj}/\tau_E$, $\tau_E \approx 3\beta\tau_K/2$). (Confinement is considered sufficient when the current-drive power can heat the plasma to the stability β-limit since further increase will not raise the plasma pressure.)

Thus, IDCD (perhaps assisted by pressure driven interchange activity) causes a current penetration that keeps the equilibrium stable to the destructive kink modes, while at high frequency the imposed fluctuations limit the damage from interchange and allow sufficient confinement[3]. At high frequency there appears to be a paced pressure release while maintaining high β. Low frequency allows time for the full development of the pressure driven mode that apparently destroys pressure confinement. Figure 9 shows the q profiles for a high and low frequency shot, two NIMROD simulations and the Taylor state. The experimentally observed profiles are kink stable. The pressureless simulations are not kink stable, but adding pressure to the simulation allows the sustainment of kink-stable equilibria.

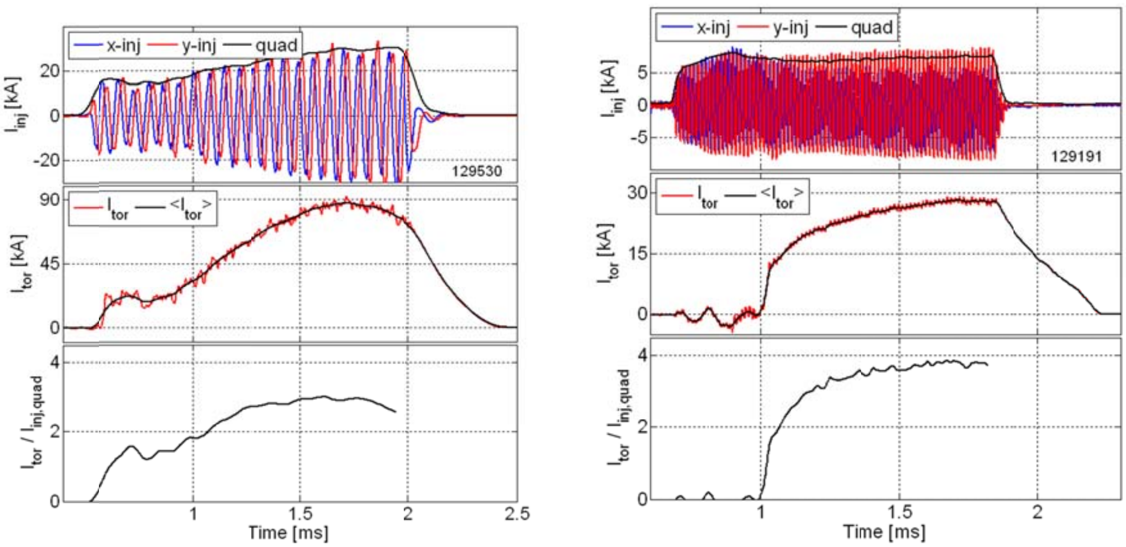


Figure 7. Injector current, toroidal current, and their ratio for a 90 kA discharge at 14.5 kHz and for a discharge at 68.5 kHz with a current gain approaching 4.

The key is keeping the profile away from the kink-unstable regions, that destroy confinement, and at the same time limit the damage from the pressure driven mode. In the correct range of injector frequencies this appears to happen on HIT-SI giving sustained sufficient confinement. A goal is to achieve this at higher parameters.

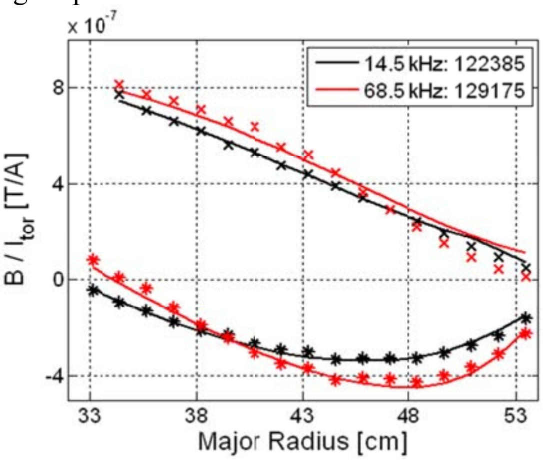


Figure 8: Toroidal (x) and poloidal (*) equilibrium magnetic fields measured by the internal magnetic probe normalized by toroidal current. Error bars are smaller than the data points. The solid lines show the Grad-Shafranov profile of the fit to the data. $\beta_{14.5}$ = 0%. $\beta_{68.5}$ = 28.9%. $t_{14.5}$ = 1.50 ms, $t_{68.5}$ = 1.65 ms.

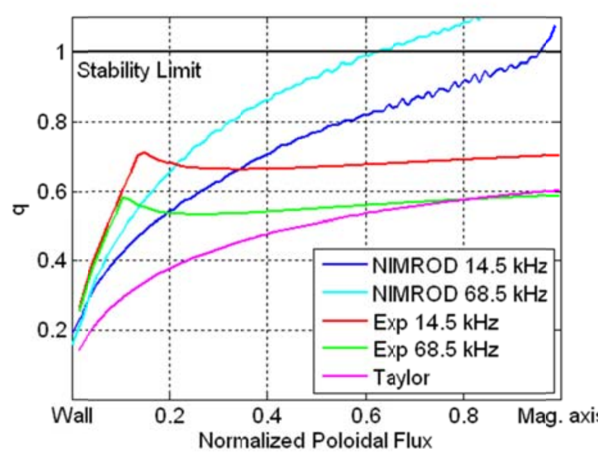


Figure 9. q-profile from the 14.5 and 68.5 kHz NIMROD simulations, experimental data at 14.5 and 68.5 kHz, and the Taylor minimum energy state. The experimental data, with q < 1 everywhere is n = 1 kink stable and with q_{max}> ½ is n = 2,3,… kink stable.

4. New activities

4.1. Installation of new injectors:

Figure 10 HIT-SI3 the present experiment.

A new injector arrangement with three smaller injectors has been installed on one side shown in Figure 10. We delayed installing the new injectors because we achieved current gain of 3 on HIT-SI and needed more time to study this new regime. The experimental plan is to study and develop the potential advantages of HIT-SI3.

Three injectors are placed on one side, giving several potential advantages. a) The plasma can be rotated, for stability against resistive wall modes, by driving the injectors 120 degrees out of phase like a three phase motor. b) Injectors have the same preferred current direction for improved synergy among the injectors.[26] c) Axially symmetric coils can be used to prevent equilibrium fields from diffusing into the injector volume, for long pulse operation. d) The other side is free to try a perforated plate backed by a pumped chamber for density control. e) These new injectors have a larger radius on the transition from injector to chamber and care is being taken to apply a solid coat of plasma sprayed insulating coating. We have found that coating sprayed on at 45 degrees is porous and does not insulate the plasma from the copper very well. The new injectors will only rely on coating applied at near normal incidence. This may allow higher power for more time. f) HIT-SI3 will have gas valves that can be controlled during the discharge for better density control. In addition, all of the gas will flow into the injector halfway between the openings for maximum utilization. Definitive measurements of gas requirements will be made on this experiment. g) By changing the phasing of the injectors, we can test and develop profile control because the imposed fluctuation profile depends on the phase of the injectors.

4.2. Applying IDCD to other devices:

An IDCD injector could be attached to a tokamak as in Figure 11. Because the injector flux and current both reverse each half cycle the tokamak current is always driven in the same direction. On HIT-SI currents of $8qI_{inj}$ have been achieved and CHI has achieved gains of 50 or more on spherical tori so a modest injector current can drive currents in the MA range. The power efficiency can be a few 10s of percent making it an attractive startup and current drive method. The imposed fluctuations on a stable equilibrium should not damage confinement as indicated in simulations. The injector can be installed on large ports in present tokamaks and ITER and Figure 11 has an oversize injector. The largest technical question is will the injector operate in a large transverse B-field. If not then bucking coils would need to be added to exclude the field without introducing unacceptable field errors on the tokamak. However, the possibility of solving the current drive problem and stabilizing a host of other instabilities may make it worth the effort. As with RF coupling the optimum placement of the injector with respect to the scrape-off layer will need to be determined experimentally. Thus a movable mount would be desired. When doing CHI on an ST, large currents can be driven stably in the edge[27]. IDCD of the stable equilibrium might be done by using RMP coils to impose fluctuations while running CHI. We are proposing to try this on NSTX-U.

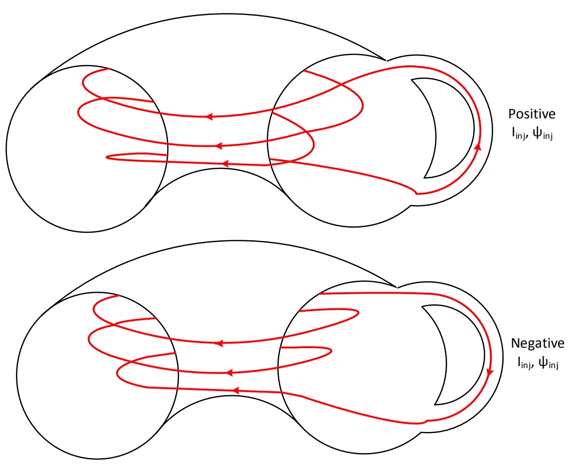


Figure 11. Applying IDCD to a tokamak

In a companion initiative white paper, we propose applying IDCD to a larger spheromak where temperatures in the kilovolt range are produced for seconds. Such a demonstration of IDCD may be necessary to prompt its use on tokamaks.

4.3. Theory and Computation

NIMROD 2-fluid simulations: Quantitative comparisons between the simulation output and various diagnostic measurements are possible. Figure 12 and Figure 13 show comparisons of mid-plane measurements of the poloidal and toroidal fields from the internal magnetic field array (IMP) with synthetic probe output from the 13-eV 2fl-MHD simulations.

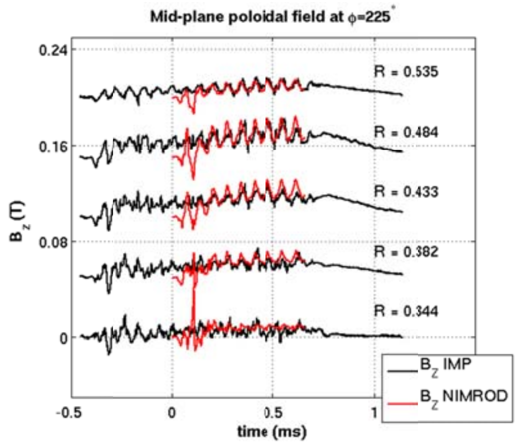


Figure 12: Time traces of the mid-plane poloidal magnetic field B_z at five different radial locations as measured by the IMP and calculated from a 13-eV 2fl-MHD simulation.

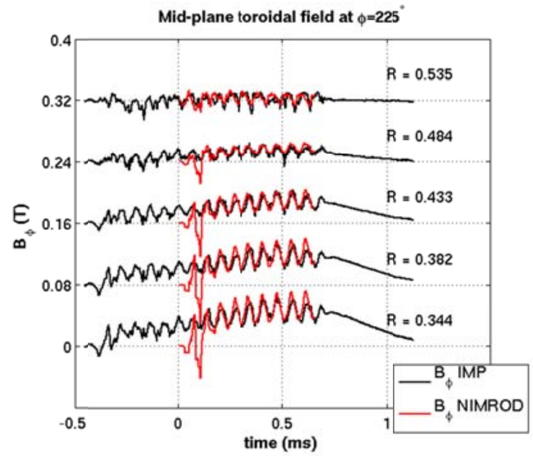


Figure 13: Time traces of the mid-plane toroidal magnetic field B_φ at five different radial locations as measured by the IMP and calculated from a 13-eV 2fl-MHD simulation.

Developing and validating predictive capability: One goal of the HIT program is to validate MHD simulations with the experimental results. Thus we work closely with the Plasma Science and Innovation Center (PSI-Center). The PSI-Center has the goal of improving the physics, boundary conditions, and geometry of MHD codes to achieve improved predictability. *HIT-SI and HIT-SI3 are unique as testing tools because they require that the codes are able to handle arbitrary geometries; they form and sustain a spheromak inductively so electrodes do not need to be modeled and they inject helicity with a symmetry and frequency different from the equilibrium for a more definitive study of helicity injection current drive and IDCD in particular. HIT-SI is the first experiment to do IDCD.* We propose to continue to compare HIT-SI experimental data to existing predictions, to new predictions by running presently improved codes, and to future codes.

Chris Hansen and George Marklin of the PSI-Center have developed a new, modern two-fluid MHD code PSI-TET. It has a tetrahedron mesh so it can be rapidly adapted to any geometry. It uses mimetic operators to enforce $\nabla \cdot \boldsymbol{B} = 0$. It models the boundary condition of insulator coated conductors and it has higher order elements for modeling transport. It has Braginskii resistive heating and thermal transport. No other MHD code has all of these necessary features needed for modeling HIT and future IDCD experiments. PSI-TET is being verified, using NIMROD as a standard, on the HIT geometry with the same physics assumptions with extended MHD. PSI-TET has added the modeling of the injectors and the insulated-conductor wall. The profile agreement will be an important test. By the end of the next grant period, the PSI-Center plans to add the **external circuit**; and the **interacting neutral fluid dynamics** (now in 2D HiFi) and validate with HIT-SI and HIT-SI3 data. These features are necessary to model the rotation we expect with IDCD and to model the edge, which needs to have high edge temperature to minimize the Ohmic dissipation in the edge. All the features are being verified and validated on HIT. The

PSI-Center is in the process of validating the code on the EPR experiments of the Lithium Tokamak Experiment (LTX) and the High Beta Tokamak (HBT).

Our present effort in validation is predicting the magnetic and velocity fields and the temperature given the injector current and flux and initial and boundary conditions of density. Adding the new features allows the next step of predicting the magnetic and velocity fields and the density evolution given the injected gas, the recycling rate, the circuit excitation and Braginskii transport. Modeling the recycling rate will be started.

5. Summary of the HIT program plan.

The HIT program is focused on developing IDCD on a low-aspect-ratio symmetric torus called a spheromak with applications to RFPs and tokamaks. The plan is as follows; 1) validate a 3D two-fluid MHD code that models the injectors, the insulated boundary, the external circuits, the full geometry, interacting dynamic neutrals, and transport with special attention to the edge; 2) develop and validate a method of rapidly predicting the current profile produced by a given flux conserver and injector array and test profile control; 3) improve the HIT-SI3 machine performance including better density control and testing the effects of imposing rotating fluctuations; and 4) improve the plasma diagnostics for more scientific information. The goal is a better understanding of IDCD and magnetic fluctuations in general while developing the inductively sustained symmetric torus concept. New understanding, new data, and more predictive codes provide the scientific bases for improving machine performance.

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