Summary of WG1
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I. Introduction and summary

This working group had discussion of current drive that drives the bulk of the electron distribution (necessary for reactor relevant current drive) and alternative concepts that might be applicable to the NSTX tokamak experiment. During the closed session Professor T. R. Jarboe discussed the Proposal to form and sustain the NSTX plasma with CHI; Dr. F. M. Levinton presented the Proposed Development of MSE for q-profile Measurement at Low Magnetic Field; Dr. K. C. Shaing talked about 100% Bootstrap Current Startup in NSTX; Dr. R. Maqueda presented on behalf of the Los Alamos Group a proposal on Fast Visible and Infrared Diagnostics for NSTX; Dr. M. Yamada covered Extended Low-q Start-up Operation of NSTX, Including Spheromak Regime; and Dr. H. Ji discussed Low-q, Ultra-low-q Operations and ST Without Center Stack.

The needs for this working group were discussed and some details needed for CHI are given in section II. The diagnostic needs were also discussed and the lack of early internal magnetic diagnostics seems to be the only recognized fatal flaw in the experimental plan. For any new current drive scheme the internal profile is unknown and needs to be measured and in the case of CHI the magnetic activity needs to be studied up to 100kHz. The group was impressed with the possibility of using LIF/MSE of equilibrium measurements and the Transient internal probe TIP for studying magnetic activity. The group recommends that these two concepts be developed into useful diagnostics.

II. Proposal to form and sustain the NSTX plasma with CHI, Tom Jarboe and Roger Ramon

Coaxial Helicity Injection (CHI) has successfully formed and sustained the Helicity Injected Torus (HIT) equilibrium. Toroidal plasma currents of over 200kA have been achieved with electron temperatures in the 100eV range and electron density between $10^{19}m^{-3}$ and $10^{20}m^{-3}$. No transformer was installed on this experiment. The major radius of HIT is 0.3m and the minor radius is 0.2m making it a spherical torus of aspect ratio 1.5. We propose to use CHI to startup and sustain the NSTX plasma in the 500kA range. Assuming helicity balance and energy conservation the following conditions need to be met:

a) I_{inj}/ψ_{inj} must be greater than $I_p/\phi_{toroidal}$. From experience a factor of 2-2.5 is needed thus $I_{inj}/\psi_{inj} \cong 2.5$MA/Wb.
b) The injector current must exceed the required to stretch the injector flux away from the injector.
c) During formation the helicity (K) required for the current in the tokamak must be injected. Thus $2V_{inj}\ \psi_{inj}\ \Delta t > K$ ($\cong 0.5\ Wb^2$) as long as the formation time (Δt) is short compared to the helicity decay time τ_K. The old S1 bank of 15mF at 20kV with a

series inductance of 300μH should be adequate for the job. Something like 1kV for 5ms will be applied with ψ_{inj} of 50mWb and I_{inj} about 140kA.

d) During sustainment the helicity injection rate must balance the losses ($2V_{inj}\ \psi_{inj} = K/\tau_K$). Using a 20kA supply at 1kV with ψ_{inj} of 8mWb will sustain the plasma as long as the current decay time is greater than 3ms.

We had an extensive discussion of things that need to be done for CHI on NSTX. The following needs were thought of:

a) 20,000 torr liters/s gas flow from four symmetrically mounted gas valves (5000t l/s valve). On the inboard electrode only 5ms -10ms puff lengths are needed;
b) Over voltage protection of centerstack;
c) ECH preionization;
d) Two SSI source on outboard electrode;
e) Interlock CHI with tf current;
f) Protect metal bellows and ceramic break;
g) Deal with interference between startup equilibrium and rf antenna;
h) Maintain voltage between divertor strike points; and
i) Develop run plan.

III. Proposed Development of MSE for q-profile Measurement at Low Magnetic Field, Fred M. Levinton, Fusion Physics & Technology

The MSE technique, which has been very successful at measuring the magnetic field pitch angle on high field experiments, can be extended to low magnetic fields (< 3 kG) in two ways. The conventional collisional fluorescence approach (MSE/CIF) has to be modified to reduce the geometric Doppler broadening effects. This can be done using front-end optics with a narrow aperture. This reduces the geometric Doppler broadening to allow measurements done to a magnetic field of 3 kG. Numerical modeling of this configuration predicts a polarization fraction of about 30% and, with improved throughput and narrow band-pass filters, a measurement accuracy for the magnetic pitch angle of 0.1 degrees is possible with a time resolution of a few milliseconds. A second approach to enhance the MSE system is to use laser induced fluorescence (LIF). This technique uses a compact CW neutral beam and laser pumping to excite the n=2-->n=3 transition and then observe the fluorescence. The laser polarization is rapidly rotated and when it is aligned with the local magnetic field the fluorescence will be at a maximum. Using synchronous detection the phase of the fluorescence will then determine the magnetic field pitch angle. Using a collisional radiative model an enhancement factor of 2-3 over the collisional fluorescence is expected. This, combined with other improvements in the throughput can result in an uncertainty and time resolution that is comparable to the MSE/CIF approach. The MSE/LIF approach has several advantages. The use of a compact CW neutral beam allows measurements of the q-profile evolution without the use of the heating neutral beam. This would be valuable for studying plasma start-up with helicity injection or RF current drive. With the narrow spectral line width the MSE/LIF approach can also be used to measure the toroidal field. This provides a measure of diamagnetic effects and can be used to infer the pressure profile. Also, combined with the MSE/CIF measurement the radial electric field can be measured. Finally, with a small diagnostic beam based system the diagnostic is also applicable to other smaller scale projects that have low magnetic fields.

IV. 100% Bootstrap Current Startup in NSTX *, K. C. Shaing#, A. Y. Aydemir# and Y.-K. M. Peng+

Self-sustained steady state tokamak equilibria for NSTX are calculated by coupling potato bootstrap current in the near-axis region to the conventional banana bootstrap current in the region away from the axis. It is demonstrated that the amount of the pressure gradient driven current which includes bootstrap current and diamagnetic current is comparable to the designed current specification. Thus, steady state NSTX plasmas can be sustained, in principle, without external drive. By increasing plasma beta with external heating and fueling and by proper control of plasma profiles to avoid micro instabilities and MHD instabilities, one can also start up NSTX plasmas without external current drive. Because the current density profile is hollow, the safety factor q profile is reversed. The reversed q profile may have favorable instability property. If the resistive diffusion time is shorter than the profile evolution time (slow startup), the startup process can be illustrated by a sequence of equilibrium calculations. One may, therefore, be able to demonstrate steady state tokamak operation in NSTX.

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+Princeton Plasma Physics Laboratory (on assignment from Oak Ridge National Laboratory).

V. Fast Visible and Infrared Diagnostics for NSTX, Ricky Maqueda and Glenn Wurden

The two diagnostics systems may be useful in the study of current formation and sustainment by means of coaxial helicity injection. The first diagnostic system uses a Kodak EktaPro fast visible digital camera to image the helicity injector and so study gas breakdown and dynamics in the injector as well as the influx of impurities and fuel from this injector. This system will also be useful in assessing perturbations to the edge plasma induced by MHD modes, like the n=1, that may be related to injection of helicity. The camera owned by LANL (EktaPro EM1012) is capable to taking up to 1000 full frames per second (and up to 6000 partial frames per second) with exposures down to 10 microseconds and storage capacity for 1638 full frames. (A full frame being 8 bit in depth and (239x192 pixels.) The plans for an upgraded system with a new EktaPro HS4540 camera were also presented. This last camera is capable of taking 4500 full frames per second (and up to 40500 partial frames per second) with exposures down to 10 nanoseconds and storage capacity for 5120 full frames.

The second system uses an Amber Radiance IR camera to look for hot spots in the coaxial helicity injection electrodes that may be sources of impurities as well as increased thermal loads on the plasma facing components due to CHI related MHD modes. LANL owns a Radiance 1 IR video camera (60 Hz frame rate) with 12 bit digital output that is suitable for these measurements. Plans for the acquisition of an upgraded camera (Radiance HS) capable of running at 120 Hz at full frame and 1400 Hz with partial frame were also presented. In both these cameras a full frame image is formed by 256x256 12-bit pixels.

VI. <u>Extended Low-q Start-up Operation of NSTX, Including Spheromak Regime,</u> M. Yamada

<u>Major Physics Issues;</u>
[1] How does the plasma stability property change from spheromak regime to ULART regime?
a) Global MHD stability; n=1 tilt/external kink modes
b) Low-n MHD modes
c) Features of self-organization
[2] How does formation characteristics change from Spheromak to ULART with without CHI?
[3] How does ULART's high-shear configuration relate to spheromak?

VII. Low-q, Ultra-low-q Operations and ST without Center Stack, Hantao Ji

1. Past LQ and ULQ research at large aspect ratio: quiescent ($b/B < 1\%$) and globally stable discharges (no disruption) were obtained. Stability analysis showed that a narrow stable window exist at $q_a = 0.7$ for n=1-5.
==> LQ/ULQ-ST should be studied theoretically and experimentally:
(1) MHD stability,
(2) Avoidance of relaxation by profile control,
(3) Confinement and beta-limit

2. Two schemes on ST without center stack have been examined. SPHERA scheme uses screw pinch to replace TF coil and P. Kaw's scheme uses force-free spheromak shell to replace TF coil. The major difficulties are power and stability:
- ST plasma has to be stable
- Central (or shell) plasma has to be stable
- Both plasmas have to be stable as a combination

==> LQ/ULQ-ST may make these issues easier: need to be further examined.