Issues Regarding Plasma Formation and Current Sustainment by Slow (MHD) Mechanisms

Working Group I

National Spherical Torus Experiment Research Forum

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Creative and fruitful discussions were made in Working Group-1 to make NSTX exciting & productive device. WG-1 had two tasks. One was to discuss current drive methods that produce the bulk electrons using slow or MHD mechanisms. (Current drive schemes with RF waves and NBI are covered by WG-2.) The other task was to discuss the possibility of studying alternate concept physics in the NSTX device. The capabilities to be built into this device make it attractive as a platform to study many of the alternate concepts.

Current Production via Transformer Induction

The (slow) MHD formation methods discussed for NSTX were the standard inductive transformer drive (OH), Coaxial Helicity Injection (CHI), and spontaneous current drive or pressure driven current. Stan Kaye gave a talk about the OH calculations that were done. Because of the large amount of experience with the use of a transformer there is little doubt that this method will work to produce high current plasma on day one. This startup assumes a 0.2-sec ramp-up to 1 MA followed by a 0.45-sec flat top. The ramp up consumed 0.7 Vs and the flat top 0.3 Vs. There was some concern that consuming 70% of the volt seconds for startup did not leave enough margins for uncertainties. On the other hand, it was pointed out that extra volt seconds could be obtained by starting with a large major radius and compressing. K. Wong pointed out that an adiabatic compression is attractive because it would provide a much denser and hotter target plasma for the neutral beams at start-up. The NBI would then fill out the bulk plasma using the target as the seed. Rather than attempting the challenging task of increasing the toroidal field directly, a programmed vertical field could instead be used to push an initial plasma inward to smaller major radius, and hence into a larger toroidal field. However, for engineering reasons and for going to even lower aspect ratio the OH coil is undesirable.

Coaxial Helicity Injection

Mike Schaffer and Tom Jarboe led the CHI discussions. CHI startup and sustainment have been achieved on DIII-D and HIT. Although up to 250 kA have been achieved on HIT and 15 kA on DIII-D the method is still under development and the following unresolved issues will be studied on both NSTX and HIT-II:

a) The current profiles produced tend to be hollow. However, just how hollow they are and how the profile shapes will change with size and resistivity are not known.
b) The relaxation activity that is required for driving current on closed flux surfaces involves momentary breaking and reconnection of field lines. The extent to which this activity

degrades confinement is one of the major issues with CHI and will be studies on both NSTX and HIT-II.

c) Although the helicity transport efficiency, in principle, can be near 100% for CHI, energy lost due to relaxation activity and due to driving currents on open field lines may give considerably lower efficiency. The HIT program has had 10% energy efficiency as a goal.

d) CHI in a tokamak is accomplished by applying a voltage between the divertor strike points. This may decrease the effectiveness of the divertor and cause an increase in impurities. This has not been a problem in HIT but should not be ignored for the larger current, higher power, and longer pulse conditions anticipated in NSTX.

e) To our best understanding, the DIII-D experiment achieved only 15 kA because once the tokamak formed the strike point moved off the biased divertor, stopping CHI. HIT solves the problem by biasing very large areas and forming the x-point with the driven edge currents and the passive flux conserver, providing some strike point control. In both HIT-II and NSTX external coils in part control the x-point. Care must be taken that the ends of the open field line nearest the separatrix strike different electrodes.

f) Scrape off layer plasma impedance and stability are additional key elements of investigation for CHI.

g) NSTX provides only 2 kV for helicity injection whereas HIT needed 7 kV for breakdown. However, HIT-II has achieved breakdown at less than 1 kV. In addition, low impurity, 1 kA miniature plasma source developed by the MST group could be used to aid breakdown. Using several of these sources, low temperature plasmas have been injected in MST. They also produce Ip=5 kA for an injected current of 3.5 kA. Further tests of these sources for current drive and plasma formation aiding CHI will occur in the near future in collaboration with the HIT-II group.

P. Bellan pointed out that the physics of solar prominence is similar to helicity injection and it may well be rather a bursty process involving filamentary currents rather than the uniformly distributed currents envisaged in existing models. Recent experiments at Caltech indicate that these filaments often do not follow the intended path from the electrodes, but instead develop complicated detours to adjacent wall surfaces before ultimately making their way into the bulk plasma. Bellan also pointed out that magnetic reconnection involves transient changes in parallel current at the reconnection layer. If the reconnection is patchy, the reconnection layer will have finite parallel extent. This localized transient parallel current associated with patchy reconnection should radiate shear Alfven waves. It is postulated that the radiation resistance associated with this Alfven wave radiation could act as the anomalous resistance needed for the flux annihilation required for magnetic reconnection to proceed.

The vacuum field of the spherical torus has a very high mirror ratio. This allows initial toroidal plasmas to be formed and heated without plasma current. This was done in CDX-U and plasma current was generated. F. S. Tsung discussed a mechanism for generating current via an imbalance in the loss of co- and counter-going electrons. Their Monte-Carlo calculation gives some very interesting results.

Another alternative method for helicity injection (discussed by H. Ji) is the use of flux core which may avoid impurity injection problems and could be used for oscillating field current drive. But the required change in hardware is rather large so that this option should be left for the future phases of NSTX.

Proof-of Principle Tests of Compact Toroids

The possible use of NSTX to advance the physics of the compact toroids, namely, the spheromak, the FRC, the spherical RFP, and the spherical stellarator was discussed. M. Yamada proposed that spheromaks could be injected from the top and bottom of NSTX and allowed to merge. It is very useful to explore the commonality and the relationship between ST and low-aspect-ratio compact toroids which include a low aspect ratio RFP, since this should provide the broadest scientific data base for compact fusion energy cores for future power plants. Presently conceived technique of coaxial helicity injection for NSTX is well suited for formation of spheromak and FRC plasmas as well. The up-down symmetry being built into the NSTX device will make it possible to make two-spheromak merging with its helicity-injection guns. But because one of the gun electrodes is always attached to the ground potential, only a counter-helicity merging experiment is allowed. This would lead to the formation of FRC plasma with or without a stabilizing central conductor post. We could also inject a spheromak utilizing one of the coaxial guns with or without applying an initial toroidal field. MHD beta limits for spheromak plasmas at high current densities can be tested in NSTX using the added inductive current drive of the solenoid and the added heating by NBI. A significantly increased pulse length for the spheromaks may result. A series of merging experiments have been carried out to successfully form FRC configurations by merging two spheromaks that contain opposing self-generated toroidal magnetic fields. High ion temperature was obtained during this formation process of FRC's, and the origin of the observed enhanced ion energy was attributed to the annihilated toroidal fields during the process of magnetic reconnection. In NSTX, we could create an FRC with toroidal currents of up to 500 kA and with separatrix radius of R_S=60-90 cm.

H. Ji discussed the concept of forming spherical RFP plasmas in NSTX. With a close-to-unity aspect ratio, RFP likely have only two unstable modes, whose resonant surfaces are too distant to form a stochastic region to cause parallel plasma losses. An RFP with few unstable modes is also amenable to feedback stabilization. An edge helicity source would be needed to replace the dynamo action in order to stabilize tearing modes completely in RFP. The edge helicity source can be either RF or plasma guns developed in MST. J. Sarff pointed out that ramping down TF coil current rapidly from a spherical torus plasma could result in toroidal current drive for spheromak or RFP formation, if the plasma evolves in a "relaxed state." This idea is partially tested in MST. Fast TF current ramp down would also provide inductive poloidal current profile control. Bick Hooper showed that active control of current profiles in a spheromak could create a non-monotonic lambda profile that can be optimized to confine the highest beta plasma.

P. Moroz discussed the advantages of using extra outboard stellarator windings (OSW) in NSTX to produce initial closed flux surfaces for easier plasma startup. He presented results of calculations for NSTX with two types of OSW: the standard-stellarator-type OSW and the torsatron-type OSW. In both systems, the vacuum flux surfaces without magnetic islands and with significant enclosed volume have been found. He suggested that using OSW during ohmic plasma start-up might save significant amount of Volt-seconds, while using OSW together with the ECR or CHI start-up techniques could reduce the required power significantly.

WG1 Recommendations

WG1 makes the following recommendations concerning the NSTX machine and diagnostics:

a) To test other alternative concepts, NSTX should be made more flexible. Examples include adding a modest upper PF1B coil, installing an oblate flux conserver (OSW), or connecting the TF coils in parallel for ramp down and reversal of the TF in about 10 ms (or less than a resistive decay time of the plasma).

b) The day-one diagnostics seem fairly complete except for the internal magnetic field measurements. We do not feel that Polarimetry or MSE will give the time and spatial resolution needed for studying relaxation activity and profile evolution. We recommend flush-mounted Langmuir probes in divertor plates and/or electrodes, reciprocating probes, and the Transient Internal Probe (TIP) diagnostic.

Summary

In summary, NSTX can be started up with OH; CHI application to NSTX will be challenging and scientifically exciting; and the geometry and capabilities of NSTX makes it an attractive machine to prove the scientific principles of many alternate concepts. We recommend that NSTX should have flexibility initially built in to allow future alternate concept experiments.

The synopses of the presentations are attached in the following pages

Proposed program for WG-1 breakup session.

1) General Discussions
- **T. Jarboe**
- **M. Yamada**

2) Tokamak Startup
- **S. Kaye/ M. Ono**
- **K. Wong**

3) Coaxial helicity Injection
- **T. Jarboe**
- **M. Schaffer**
- **P. Bellan**
- **J. Sarff**

4) Alternate concept research
- **M. Yamada**
- **H. Ji**
- **P. Moroz**

5) Special Comments
- **B. Hooper**
- **P. Bellan**

6) Discussion of response to chits
Preparation of summary report

CHI Science Program

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The most important issues with CHI current drive are a) the current profiles produced, b) the impact of the current drive method on confinement, c) the CHI power balance and d) and the current drive efficiency. The answer to these questions are expected to depend on the plasma parameters as well as the machine size and geometry. Also it might be difficult to determine the impact of CHI on confinement because CHI will change the profile which will also impact confinement. This study is relevant to ST fusion because CHI may be a key ingredient in the startup and sustainment of ST current. Results from NSTX and HIT-II can be used to study the scaling of CHI.

One of the most important determinations will be that of the plasma current or the magnetic field profile. Surface magnetic fields probes and flux loops plus some internal magnetic field measurements used with an equilibrium solver will be needed. The magnetic diagnostics need to be sensitive to magnetic activity up to 100kHz in frequency so that relaxation activity associated with CHI can be studied. The transient internal probe might be appropriate for these measurements. Of course, the standard temperature and density profile information is also needed. The plasma parameters and operating conditions are not too important as long as the plasma is not dominated by low-Z radiation. A range of Lundquist numbers and high Lundquist numbers are desirable.

Study of Compact Toroid Configurations in NSTX with NBI

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Compact toroids, such as FRC (field reversed configuration), spheromaks, and RFP (Reversed Field Pinch) have been extensively studied in recent years in search for a cost-effective, high-performance and high power density reactor cores. They can confine high beta plasmas with and without large elongation. FRC and spheromak configurations, which do not require external toroidal coils, have significant reactor advantages, but they can suffer from serious global MHD instabilities.

It is very useful to explore the commonality and the relationship between ST and low-aspect-ratio compact toroids which include a low aspect ratio RFP, since this should reveal the highest advantages of each concept for compact reactor design. We propose experimental studies of this important area on NSTX in this talk and in an accompanying paper by H. Ji.

Presently conceived technique of gun injection for NSTX is well suited for formation of spheromak and FRC plasmas as well. The NSTX device symmetrical ends making it possible to make two-spheromak merging with its helicity-injection guns. But because one of the gun electrodes is always attached to the ground potential, only a counter-helicity merging experiment is allowed and it would lead to the formation of FRC plasma with or without a stabilizing central conductor post. We could also inject a spheromak utilizing one of the coaxial guns with or without using the center stack. An MHD study can be carried out on the high current density spheromak produced in NSTX with additional inductive current drive by a center stack and with NBI. Utilizing a center stuck and/or NBI the duration of plasma can be significantly extended.

A series of merging experiments have been carried out successfully to form FRC plasmas by use of merging of two spheromaks with opposing magnetic field [1,2]. High ion temperature was obtained during this formation process, and the origin of the observed enhanced ion energy was attributed to the annihilated toroidal field during magnetic reconnection. In NSTX, we could create an FRC with toroidal currents of up to 500 kA and with separatrix radius of R_S=60-90 cm. The gyro-radii of ions are expected to be significantly smaller (by factor of 100) than R_S. We also expect to attain high beta plasmas ($\beta \sim 1.0$). Significant tests of MHD global stability of FRC with NBI can be therefore carried out in the regime of reactor relevancy. This would be a new regime of FRC never studied before.

A low aspect ratio RFP has never been studied before. By programming TF and PF coil currents, NSTX can create a low aspect ratio RFP. Usually the theory for RFP neglects the effect of toroidicity because of theoretical complication and because of unavailability of experimental data in this regime. The unique characteristics of ULAR-RFP, in which only a few resonance surfaces (of n=2, 3, ..) are located in the core plasma, could have notable advantages for MHD stability.

An important question would be raised whether these CT plasmas are susceptible to a tilt mode. If so, in what condition can we make them stable? What is their relationship to ST? This NSTX-CT experiment with NBI would provide answers to these important questions. A TSC simulation and exploratory experiments on MRX-II ["Concept Development Experiment"] will help making the best scenario for NSTX- CT experiments.

1) Y. Ono et al. Proc. 14 th IAEA '92 Conf. Nucl. Fus. Pl. Phys. **2,** 619 (1992)

2) M. Yamada et al. Proc. 16 th IAEA Fusion Energy Conf. IAEA-CN-64/CP 19 (1996)

Experiments Involving Helicity Injection and Theories of Magnetic Reconnection

Paul Bellan, Caltech

Two topics will be discussed:

1. Experiments involving helicity injection

Experiments now underway at Caltech have the goal of observing what actually happens when helicity is injected. The experiments are performed on two guns: (i) a conventional coaxial spheromak gun, and (ii) a non-coaxial gun intended to simulate solar prominence eruption. High-speed photographs clearly show twisted flux tubes with handedness determined by the gun bias field. It is observed that helicity does not flow continuously and smoothly from the guns, but instead involves discrete bursts of instabilities. Of special note, currents do not necessarily flow along the intended path from one gun electrode to the other but instead typically develop more complicated flow patterns. The fact that flux tubes emanating from a helicity injector develop unforeseen topologies should be relevant to CHI designs for NSTX.

2. Theories relating to field-aligned currents, parallel electric fields, and anomalous resistivity associated with magnetic reconnection

Magnetic helicity corresponds to field-aligned current, helicity generation involves parallel electric fields, and helicity injection involves localized magnetic reconnection. These concepts are inter-related because magnetic reconnection involves transient, localized changes in field-aligned current. In particular, if reconnection is patchy as occurs in helicity injection, the transient field-aligned current will be localized in three dimensions.

Traditional discussions of helicity injection, helicity conservation, and Taylor relaxation invoke resistive MHD. If NSTX is hot, the plasma will be collisionless, making resistive MHD inappropriate. The temptation to use ideal MHD leads to difficulty because ideal MHD assumes that the parallel electric field is short-circuited to be zero. This assumption and the associated assumption of zero electron mass lead to various non-physical singularities in ideal MHD. By including finite electron mass and non-zero parallel electric fields, two-fluid theory predicts behavior that conflicts with the predictions of ideal MHD, casting doubt on the validity of ideal MHD in situations where field-aligned currents and parallel electric fields are important.

Using two-fluid theory it is shown that a transient, 3D-localized field-aligned current radiates torsional Alfven waves and experiences an associated radiation resistance; these effects are not predicted by MHD. It is postulated that this Alfven-wave radiation resistance provides the localized energy sink (i.e., an anomalous resistivity) necessary to mediate patchy reconnection in a collisionless plasma. Hence, helicity injection may involve radiation of shear Alfven waves from the regions where the magnetic topology is changing.

A COMPACT PLASMA ELECTRON SOURCE FOR PLASMA FORMATION AND CURRENT DRIVE

John Sarff, University of Wisconsin-Madison

The MST group has developed a compact, radially insertable plasma source for electrostatic current drive. This source is being used principally to control the edge current profile in the RFP for MHD fluctuation reduction, but it might be well suited to other fusion applications, including plasma formation, current drive, and plasma biasing in a spherical tokamak. Cathode emission from a small gas-fed arc discharge inside the source has advantages of high current (1 kA), high current density (>100 A/cm^2), low impurity generation, and compactness (4 cm dia.). In MST, 16 such sources are installed to produce a total electrostatic current injection of ~16 kA. The sources are easily rotated and radially positioned (including fully retracted) when mounted in conventional port holes. Through the auspices of a Small Business Technology Transfer (STTR) collaboration, the source will be tested alone and with CHI for plasma formation and current drive in HIT-II, and a 0.3 second pulse length design will be tested in MST.

POLOIDAL INDUCTIVE CURRENT DRIVE FOR NSTX-CT FORMATION

John Sarff, University of Wisconsin-Madison

The available poloidal flux for ohmic current drive in an NSTX-CT configuration (spheromak or spherical RFP) is extremely limited. The challenge is even greater than for ST formation since the toroidal plasma resistance will be larger in a CT, if for no other reason than increased field line length in the low safety factor CT limit. Beginning with high-q tokamak seed plasma, rapid decrease of the toroidal field provides a poloidal electric field for ohmic current drive (similar to theta pinch formation). If the plasma follows a "relaxed-state" trajectory quasi-statically, then it is possible to double the toroidal current in going from a q(a)=10*(a/R) tokamak to a q(a)=0 spheromak configuration, thereby saving precious poloidal flux-swing and/or minimizing the required non-Ohmic current formation. Poloidal inductive CT current drive has been tested in MST. As an RFP, MST has limited toroidal field capability ~800 G, so the test was limited to low plasma current and seed tokamak q~1. The increase in toroidal current from 65 kA to 75 kA was half as much as predicted by using a relaxed-state equilibrium model, which ignores dissipation. The conditions for NSTX should be more favorable for this technique (larger BT, larger q(a), and hotter seed plasma).

"OUTBOARD WINDINGS FOR NONINDUCTIVE START-UP AND COMPACT TORUS PLASMA FORMATION IN NSTX"

by Paul Moroz, Univ. Wisconsin-Madison

This proposal is focused on investigating a possibility of noninductive start-up and plasma formation in NSTX via additional windings that we call outboard stellarator windings (OSW). The main advantage of OSW is that they don't disturb the designed coil system of NSTX. Another advantage is that OSW can be powered only during the start-up phase, which will preserve the toroidal symmetry of the main operational regime in NSTX.

The principal possibility of using OSW also during the normal phase of operation might be advantageous for disruption control and for steady-state plasma sustainment. These possibilities, however, constitute additional benefits that can be explored as well.

The main principle on which OSW are based is close to that for a Spherical Stellarator (SS), a novel concept recently proposed [1-6]. Namely, OSW produce stellarator effects such as closed vacuum flux surfaces with finite rotational transform. At the same time, OSW do not require modification of the main TF coils of NSTX. There are also a few other advantages of using OSW in ST that cannot be produced in SS. On the other hand, it is difficult to make OSW in ST as effective for production of the stellarator effects as it could be done in SS.

Initial results that we are going to present at the NSTX Research Forum show the principal possibility of using OSW in ST and particular in NSTX. Two principally different types of OSW were analyzed in our numerical calculations, and both were shown can be effective in NSTX.

In this first research on the subject, we did not try to make a careful engineering design of OSW for NSTX, which would require special efforts and close collaboration with the NSTX team engineers and scientists. Instead, we considered a simplified model of the NSTX coils, which are easy to parameterize for the numerical calculations. The main goal of our proposal, however, will be to design an efficient OSW for NSTX. This work should be carried out in collaboration with the NSTX staff members to make sure that all requirements imposed by the experiment are satisfied. The actual OSW that will be a product of such collaborative design might differ significantly from the two types of OSW that we have numerically analyzed during our initial investigation. Research will also be focused on numerical modeling of the effects of OSW on particle confinement, current induction, high beta plasma equilibrium, and bootstrap current in NSTX.

References.

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[6] P. E. Moroz, Proc. US/Japan stellarator workshop (New York City, October 14-17, 1996) to be published in Plasma Physics Reports (1997).

"Helicity Injection Results from DIII-D"

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DIII-D has performed the only helicity injection (HI) experiments in a large tokamak with auxiliary heating, good confinement, H-mode and extensive diagnostics. As such, these experiments are of interest to HI on NSTX. The DIII-D experiments use an axisymmetric divertor ring electrode with the vessel as counter electrode. Principal highlights are (1) Tokamak plasma formation was successfully demonstrated using the magnetized electrode aided by ECH. (2) Several attempts at HI current drive of pre-existing tokamak plasmas so far have not been successful. (3) Attempts to force large SOL current by the electrode strongly modify the SOL, drive an unidentified instability and degrade core confinement. (4) Plasma control is difficult. Additional details will be presented. Differences and similarities with other HI experiments and NSTX will be discussed.

Adiabatic Compression During Noninductive Startup of NSTX

King-Lap Wong, Princeton Plasma Physics Laboratory

CHI has been demonstrated successfully in HIT to drive plasma currents beyond 100kA.[1] This scheme appears to be most promising for noninductive startup of a spherical torus, and it is built into the design of NSTX. Judging from the data obtained from HIT, the current density may be hollow. Compression technique has been used in START to produce the ST plasma.[2] Here we explore the possibility of combining adiabatic compression[3,4] and CHI to enhance the plasma current and obtain a peaked current density profile in the startup phase of NSTX. The scenario is described in the following:

A ST plasma at R=R1 is formed by CHI. Then currents in the EF coils are programmed to move the plasma slowly (in tens of milliseconds) out to R=R2. The plasma current may be reduced during this process. Then the EF current is raised rapidly (in a few milliseconds) to compress the plasma back to R=R1. The plasma current is expected to be enhanced in this process by the compression ratio C=R2/R1. This current is confined in a smaller current channel with the minor radius reduced by the square root of C. CHI remains on during and shortly after the compression process to produce more current outside this compressed current channel. This can result in a plasma with a total current higher than what one would have obtained with CHI alone. The current density can be peaked at the center, and the plasma density and temperature in the compressed channel will be higher. This target plasma is desirable for central power deposition from neutral beam and ICRF heating. One can inject neutral beam before compression; the beam ions will be accelerated by the compression process,[5] and these fast ions will help sustain the core temperature after compression. No additional hardware is required for this scheme. The programming capability of the EF system already exists in TFTR. The maximum compression speed remains to be determined.

References

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Spherical RFP Studies in NSTX

Hantao Ji, PPPL, Princeton Univ.

The reversed field pinch (RFP) has several attractive features as a possible fusion reactor, including weak magnetic field, high beta, high energy density. However, it suffers from a poor confinement due to parallel convective loss [1] across a stochastic region over most plasma volume. This stochastic region is due to island overlapping caused by the combination of large mode amplitudes (order of 1% of total magnetic field) and the proximity of neighboring resonant surfaces.

The conventional RFP devices have aspect ratio larger than 3 which results in a lower center safety factor q(0), leading a flatter q profile. As a consequence, a broader spectrum of unstable tearing modes is excited. In the spherical RFP configuration where the aspect ratio is approaching to unity, q(0) is raised resulting in a larger shear and smaller number of unstable modes (number=1+R/a=2) [2]. The advantage of spherical RFP can be two-fold: (1) an improved confinement is expected from a smaller stochastic region; (2) feedback stabilization is expected to be easier since only two unstable modes exist.

The RFP operation is proposed in NSTX to explore the stability and confinement of this configuration. The initial test for the spherical RFP will be carried out in MRX-II, which is under preparation of proposal. The technical requirements and detailed formation schemes will be discussed.

[1] G. Fiksel, et al., Phys. Rev. Lett. 72, 1028 (1994); M. Stoneking, et al., Phys. Rev. Lett. 73, 549 (1994)
[2] Y.L. Ho, et al., Phys. Plasmas 2, 3407 (1995)

Plasma Formation and Fueling by Flux-Core Scheme in NSTX

Hantao Ji, PPPL, Princeton Univ.

Major plasma formation schemes in NSTX have been proposed as conventional ohmic startup or by coaxial helicity injection (CHI). The ohmic startup scheme is the most established method but it consume the poloidal flux which is very precious later to sustain the plasma current over a long time. On the other hand, CHI provides an important helicity source without consumption of poloidal flux, but it may pose impurity problem since it uses electrode discharges.

At a later phase of the NSTX experiment, an alternative method to produce initial plasma is proposed to use the flux-core scheme, which employs the induction to form plasma but does not consume poloidal flux. The technique was developed in proto-S-1 device, later used in S-1 [1], and currently it is being used in MRX [2]. Formation section using flux-core is considered as separated from the main NSTX device, the formed plasma is translated into NSTX later. We note that this scheme can also be used as a way to fuel the discharges. The detailed geometrical description will be discussed.

[1] M. Yamada, et al., Phys. Rev. Lett. 46, 188 (1981)
[2] M. Yamada, et al., to be published in Phys. Plasmas.

Spontaneous Current Development in NSTX

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We would like to present our previous works in the area of non-inductive current generation in Tokamaks, and discuss the possibilities of supplying computational tools and theoretical estimates of non-inductive current generation in the ST configuration.

1. Spontaneous Generation of Toroidal Currents
Using test-particle calculations, we have shown that the asymmetric loss-cone mechanism can attribute to the spontaneous generation of currents.[1] Particle that carry a negative toroidal current are better confined than those that carry a positive current, giving rise to a net toroidal current that can be sufficiently large to close the magnetic surfaces. We found that this mechanism is dependent on the curvature drift of particles, indicating that a low-aspect-ratio toroidal configuration is more favorable for this method of current generation. This mechanism allows a spherical Tokamak to start up from zero current without the use of a transformer, thus the ST can be made more compact.

2. PIC simulations of Transport-Driven Currents
Using 2+1/2- and 3-D electromagnetic Particle-in-Cell (PIC) simulations, we have shown the existence of a dynamo generated current associated with anomalous particle transport, which is an addition to the bootstrap current, and only requires fueling and heating to maintain the pressure profile. This mechanism generates flux and thus does not conserve helicity. One can think of the plasma preferentially lose one sign of the helicity (current) and retaining the other. Rather than injecting helicity the plasma eject helicity to achieve the same result.

In 2+1/2D, the observed current was attributed to the ``preferential loss'' mechanism.[2] One key assumption in the preferential loss model is that the canonical momentum in the toroidal direction is conserved. This assumption requires spatial symmetry in the toroidal direction, and it is conceivable that the current would disappear when the simulation is extended to 3-D.[3] However, in our 3-D PIC calculations, we have shown that the current profile remain essentially unchanged with the inclusion of toroidal asymmetries. We will present our previous results and discuss the possibility of carrying out similar calculations in the ST configuration.

* Scientific issues being addressed

    - Possibility of a steady-state ST without transformer or current drive.

* Relevance to ST fusion/plasma science

    - Helicity ejection by the plasma would eliminate the need for a transformer. Allowing the ST to be more compact, it would be a simpler fusion reactor.

* Measurement needed and/or recommended

- Experiments using microwave heating and pellet fueling to demonstrate startup from zero current and maintenance of current. Computer modeling of such startup and determination of current profile and the nature of the particles ejected at the scrap-off layer.

* Plasma parameters and operating condition required

- Fully ionized plasma in the 100ev range.
- Density ~ 10^12 - 10^13
- (v_r x B_p)/c should equal to the voltage required to drive the poloidal current
- fueling by pellet injection

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