Princeton Plasma Physics Laboratory

PPPL- 4302

PPPL- 4302

Design, Installation and Performance of the New Insulator for NSTX CHI Experiments

D. Mueller, M.G. Bell, J. Chrzanowski, D. Gates, J. Menard, R. Raman,
T.R. Jarboe, B.A. Nelson, R.J Maqueda and M.J. Schaffer

March 2008

Prepared for the U.S. Department of Energy under Contract DE-AC02-76CH03073.

Princeton Plasma Physics Laboratory
Report Disclaimers

Full Legal Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Trademark Disclaimer

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

PPPL Report Availability

Princeton Plasma Physics Laboratory:

http://www.pppl.gov/techreports.cfm

Office of Scientific and Technical Information (OSTI):

http://www.osti.gov/bridge

Related Links:

U.S. Department of Energy

Office of Scientific and Technical Information

Fusion Links

Design, installation and performance of the new insulator for NSTX CHI experiments

D. Mueller[a], M.G. Bell[a], J. Chrzanowski[a], D. Gates[a], J. Menard[a], R. Raman[b], T.R. Jarboe[b], B.A. Nelson[b], R.J Maqueda[c] and M.J. Schaffer[d]

[a] *Princeton Plasma Physics Laboratory, Princeton, NJ*
[b] *University of Washington, Seattle, WA*
[c] *Nova Photonics, Princeton, NJ*
[d] *General Atomics, San Diego, CA*

Abstract— **Coaxial Helicity Injection (CHI), a non-inductive method to initiate plasma and generate toroidal plasma current, is being investigated in the National Spherical Torus Experiment (NSTX). The center stack and outer vacuum vessel are separated by insulating gaps at the top and bottom of the slim central column so that a high voltage (up to 2 kV) can be applied between them from a pulsed power supply or a capacitor bank to initiate an arc discharge. In the presence of a suitable poloidal magnetic field, the discharge is initiated at the lower gap (the injector gap) and because of the strong toroidal field develops a helical structure resulting in substantial toroidal plasma current being driven. In NSTX, up to 390 kA of toroidal current has been generated for an injected current of 25 kA. The early investigations of CHI however frequently developed arcs across the insulator at the top of the machine (the absorber gap), which terminated the desired discharge. This arcing greatly restricted the operational space available for CHI studies. During 2002, the absorber region was modified to suppress these arcs. The new design includes a new ceramic insulator on the high field side of the absorber region with a much longer tracking distance between conducting elements at the different potentials. Furthermore, two new coils were installed near the absorber to provide the ability to minimize the poloidal field connecting the center stack and outer vacuum vessel. During the subsequent experimental campaign, CHI operation was less prone to arcing in the absorber and those arcs that did occur did not terminate the main discharge.)**

Keywords- Coaxial Helicity Injection, Spherical Torus

I. INTRODUCTION

Because of the limited space in a spherical torus to accommodate an internal inductive coil, an essential feature of future spherical torus designs will be the inclusion of an effective means to initiate the plasma and to drive plasma current without relying upon inductive drive. Coaxial Helicity Injection (CHI) has been shown to be effective for initiation and for ramp-up on the Helicity Injected Torus (HIT)[1], the Helicity Injected Torus-II (HIT-II)[2] and the National Spherical Torus Experiment (NSTX)[3] to drive up to 390 kA of toroidal current[4]. More recently, the existence of persistent plasma current on closed poloidal flux surfaces after the CHI drive is turned off has been observed on both HIT-II[5,6] and NSTX[7]. Fig. 1 shows the configuration of NSTX. In CHI experiments, the center column is insulated from the outer vacuum vessel and a discharge between the outer vessel and the center column is initiated by providing a high voltage between them with either a power supply or a capacitor bank. During CHI, the inner and outer vessels are linked by poloidal flux at the bottom of the machine, the injector region, provided

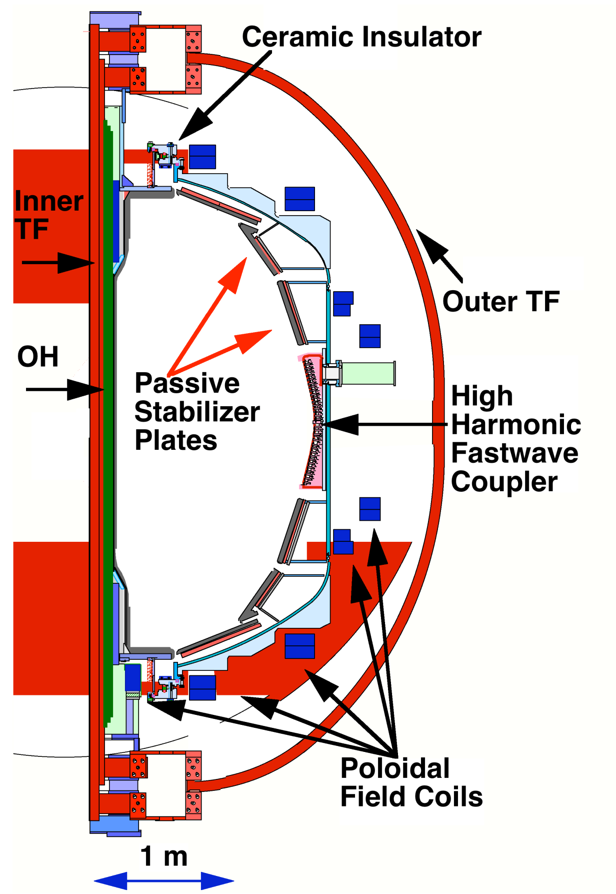

Figure 1. Cross-section of NSTX.

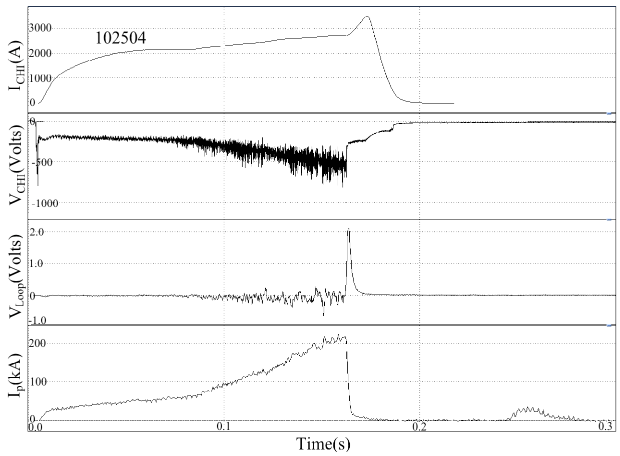

Figure 2. Low impedance absorber arc cause I_{CHI} to increase rapidly and I_p to terminate. Note the lack of noise on the V_{CHI} during the arc.

by the poloidal field coils, the toroidal coils provide a field that by itself would insulate the inner and outer vessel from each other. The net result is that the field lines connect the inner and outer walls over a helical path so that current flowing on those field lines will result in both poloidal current (I_{CHI}) and toroidal current (I_p), typically the ratio of the fields is such that I_p/I_{CHI} is around 10. The direction of the poloidal and toroidal fields and CHI injector voltage are chosen so that the $\mathbf{E}\times\mathbf{B}$ direction is up into the main chamber. Discussion of the CHI discharge evolution by magnetic reconnection from a helical arc on open field lines to a plasma with its current flowing on closed poloidal flux surfaces is beyond the scope of this paper. The reader is referred to [8] through [11] and references cited therein for further discussion on CHI discharge evolution.

II. Issue

As the plasma drifts up, poloidal flux from I_p links the inner and outer vessel at the top of the machine, the absorber region, and plasma drifting up into the absorber region provides a medium through which current can flow. This can allow an arc to form in the absorber region, which is deleterious to the desired discharge. Fig. 2 shows traces of I_{CHI}, the applied injector voltage V_{CHI}, the measured loop voltage, V_{Loop}, and Ip for a discharge taken in 2002 in which an absorber arc occurred at about 0.163 ms. Signatures of the absorber arc include a rapid increase in I_{CHI}, reduced noise on V_{CHI} and rapid termination of I_p. Fisheye TV camera views of the discharge taken at 0.162 and 0.165 s, just before and during the arc are shown in Fig. 3. Note the helical structure seen at 0.162 s, which indicates current flowing along spiral field lines. At 0.165 s, during the arc, the main discharge has all but disappeared from the TV picture and a bright, poloidally and toroidally localized arc is seen. The local non-axisymmetric nature indicates the possibility of an arc along a material surface. Such arcs have the potential to damage the machine and prevent CHI from being effectively applied. The avoidance of such arcs was difficult, they occurred on about 2/3 of all CHI discharges before 2002, despite concerted efforts to find scenarios that would avoid their occurrence.

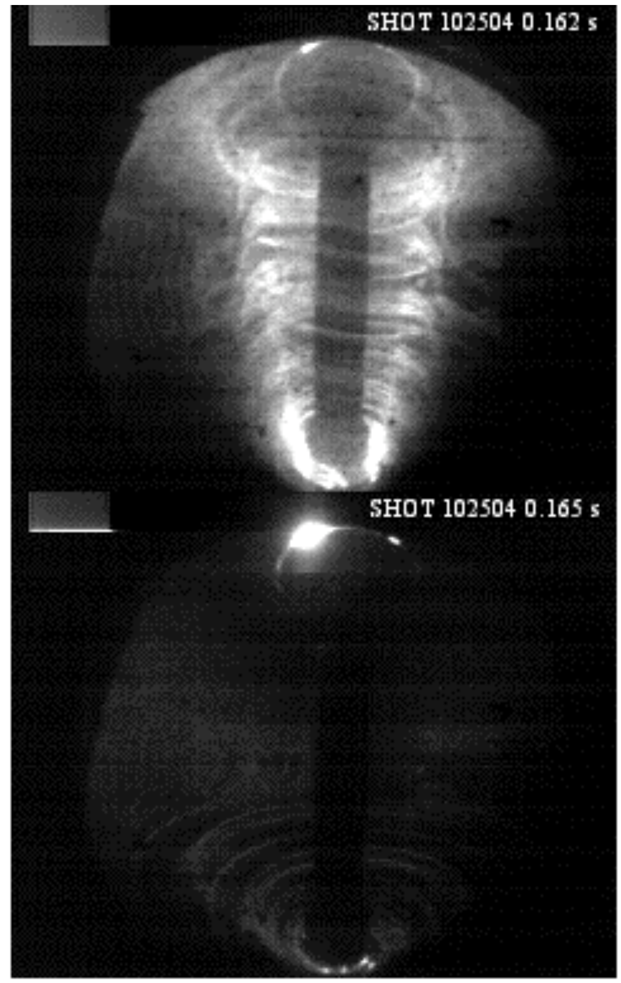

Figure 3. TV images before and during an absorber arc in NSTX before the insulator redesign.

III. Solution

In order to make NSTX more resistant to these absorber arcs, the absorber region was redesigned in 2002 based upon experience from HIT[1], HIT-II[2] and General Atomics DIII-

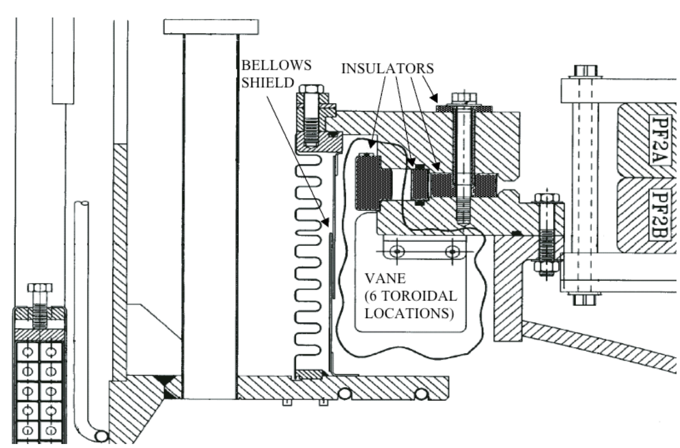

Figure 4. Design detail of absorber region of NSTX prior to 2002.

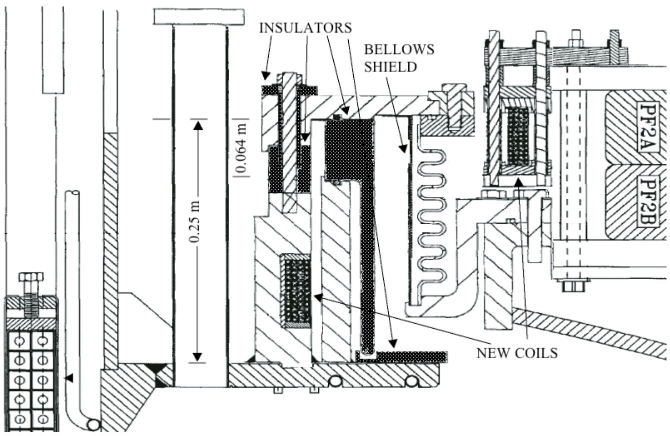

Figure 5. New absorber design in NSTX. Note the much larger insulator in the new design.

D[12] to provide an insulator on the high field side of the absorber with a much longer tracking distance between conductors. The redesign provided the opportunity to install poloidal field coils near the insulator that could be energized to minimize the poloidal field connecting the inner and outer vessel in the absorber region should that be necessary.

Fig. 4 shows the old insulator design with the insulator on the low toroidal field side of the absorber region and a short distance between the conducting surfaces. That is to be contrasted with the new design with a much longer insulating surface between the conductors at inner and outer vessel potentials shown in Fig. 5. The alumina insulator in the new design has a total height of 0.25 m and 0.0636 m between vacuum surfaces. There is also a split ceramic skirt to cover the metallic surface at the bottom of the absorber region.

After the new insulator was installed, the incidence of absorber arcs was reduced and when the arcs did occur, they had higher impedance and did not terminate the main discharge. Fig. 6 shows a shot taken with the new insulator, ICHI increases when the arc occurs and Ip is reduced, but not eliminated. Fig. 7 has TV images before and during the arc.

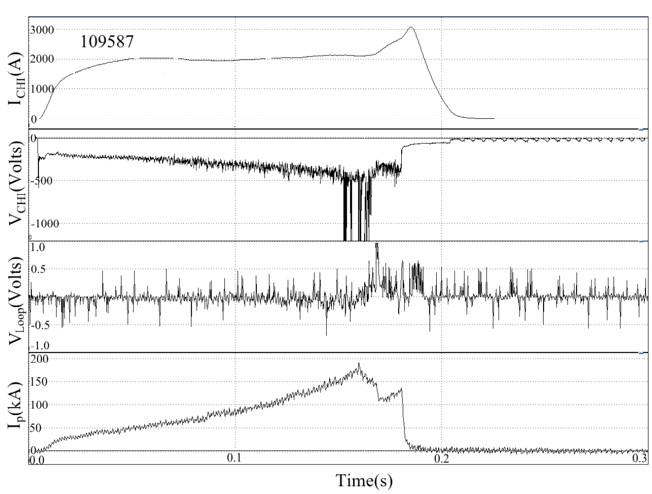

Figure 6. Absorber arc with new insulator. Note that even during the arc when I_{CHI} is increasing rabidly that the main discharge, I_p, is not terminated and the hash in V_{CHI} indicates a variable plasma load.

With the new design, it is typical that absorber arcs do not exhibit the bright, localized light seen with the previous design, but either a diffuse ring at the top of the machine or very little visible light as in this case. There has been no evidence that any damage occurred when the insulator was inspected during an opening following the run.

Since the insulator has performed well, there has been no need to use the new poloidal field coils and they remain as a backup in case a scenario is found where their use might be required.

IV. Summary

The new insulator design has performed well. The frequency of low impedance absorber arcs that terminate the main discharge has been dramatically reduced. This has permitted greater flexibility in operations, which has facilitated significant improvements in CHI operation on NSTX as evidenced by the recent results in [7]. The insulator has performed well enough that so far there has been no need to implement the new field nulling coils.

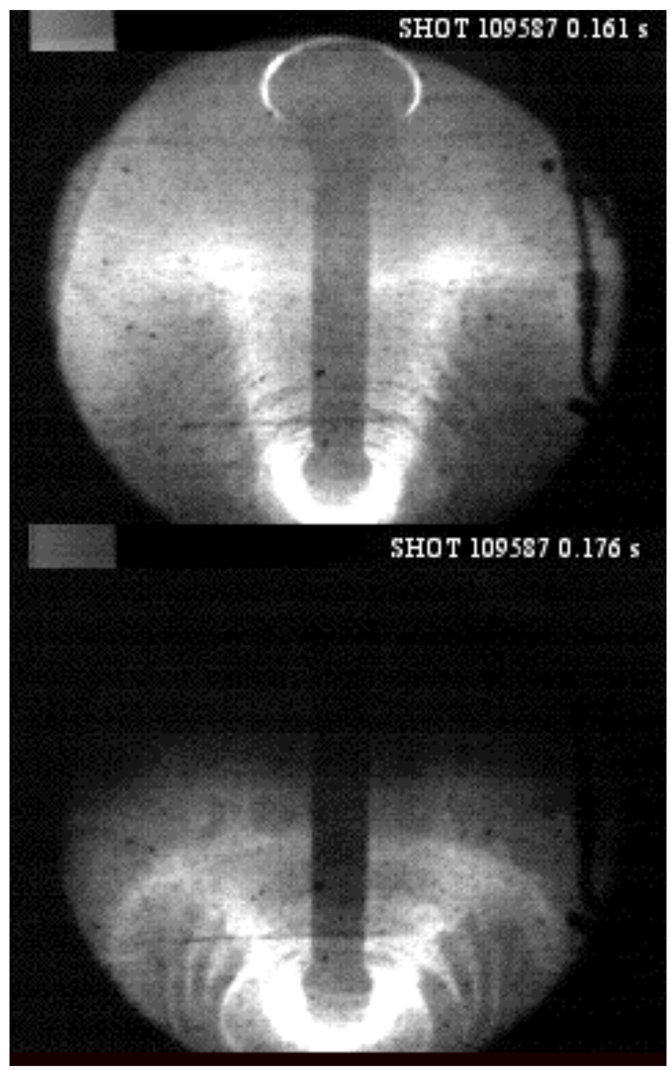

Figure 7. TV images before and during an absorber arc in NSTX after the insulator redesign. Note that there is no sign of a localized arc.

REFERENCES

[1] B.A. Nelson, T.R. Jarboe, D.J. Orvis, L.A. McCullough, J. Xie, and L. Zhou, Phys. Rev. Lett., **72**, 3666 (1994).

[2] T.R. Jarboe, M.A. Bonnet, A.T. Mattick, et al., Phys. Plasmas, **5**, 1807 (1998).

[3] M. Ono, et al., Nucl.Fusion, **40**, 557 (2000).

[4] T.R. Jarboe, R. Raman, B.A. Nelson, et al., "Progress with helicity injection current drive," Fusion Energy 2002 (Proc. 19th. Int. Conf. Lyon, 2002) (Vienna: IAEA) CD-ROM file IC/P-10 and http://www.iaea.org/programmes/ripc/physics/fec2002/html/fec2002.ht m M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

[5] R. Raman, T.R. Jarboe, B.A. Nelson, et al., Phys. of Plasmas, **11**, 2565 (2004).

[6] D. Mueller, B.A. Nelson, W.T. Hamp, et al., Phys. Plasmas, **12**, (2005).

[7] R.Raman, M.G.Bell, T.R.Jarboe, et al., "Solenoid-free Plasma Startup in NSTX using Transient CHI", proceedings of the 11th International ST Workshop, St.Petersburg, Russia, 3-6, October (2005)

[8] B.A. Nelson, T. R. Jarboe, A. K. Martin, D. J. Orvis, J. Xie, C. Zhang, L. Zhou, Phys. Plasmas, **2**, 2337 (1995).

[9] X.Z. Tang and A.H. Boozer, Phys. Plasmas, **11**, 2679 (2004).

[10] X.Z. Tang and A. H. Boozer, PRL, **94**, 225004 (2005).

[11] X.Z. Tang and A.H. Boozer, Phys. Plasmas, **12**, 042113 (2005).

[12] P.M. Anderson, C.B. Baxi, E.E. Reis, et al., "Engineering, installation, testing and initial operation of the DIII-D advanced divertor," Fusion Technolog 1990 (Proc. 16th Symp. on Fusion Technology, London, 1990), North Holland (1991), **1**, 336.

The Princeton Plasma Physics Laboratory is operated
by Princeton University under contract
with the U.S. Department of Energy.

Information Services
Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, NJ 08543

Phone: 609-243-2750
Fax: 609-243-2751
e-mail: pppl_info@pppl.gov
Internet Address: http://www.pppl.gov