Princeton Plasma Physics Laboratory

PPPL- 4281

PPPL- 4281

Design and Performance of NSTX Movable GDC Probe

H. W. Kugel, R. Maingi, M. Bell, W. Blanchard, D. Gates, R. Gernhardt,
T. Holoman, G. Labik, T. Provost, A. L. Roquemore,
and P. Sichta

January 2008

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

Design and Performance of NSTX Movable GDC Probe

H. W. Kugel,[1] R. Maingi,[2] M. Bell,[1] W. Blanchard,[1] D. Gates,[1] R. Gernhardt,[1]
T. Holoman[1], G. Labik,[1] T. Provost,[1] A. L. Roquemore[1], P. Sichta[1]
[1] *Princeton Plasma Physics Laboratory, Princeton, NJ 08543, USA,*
[2] *Oak Ridge National Laboratory, Oak Ridge TN, 37831 , USA,*
[1]hkugel@pppl.gov

Abstract--The NSTX GDC system has been improved by replacing one of the two fixed anodes with a Movable GDC Probe (MGP) anode that can be inserted 1.2 m to about midway between the inner and outer vessel walls. The purpose was to provide more spatially uniform HeGDC for improving discharge stability and reliability. The MGP has been used reliably between every discharge during the last two NSTX experimental campaigns. It has also been used to apply HeGDC assisted boronization, and more recently, HeGDC assisted lithiumization. The MGP has contributed to improved NSTX performance during long pulse and H-mode discharges, and enabled a faster discharge repetition rate.

Keywords-component; wall conditioning, impurity control, glow discharge cleaning, tokamaks

I. INTRODUCTION

During National Spherical Torus Experiment (NSTX) plasma operation from 1999 to 2005, the Glow Discharge Cleaning (GDC) system (Fig.1) was configured with two stationary anodes, fixed to the vessel outer wall near the midplane, on nearly opposite sides of the vessel [1]. This system was used for Helium Glow Discharge Cleaning (HeGDC) between plasma discharges and for boronization using a mixture of 5% deuterated-trimethyl boron in 95% helium. Two DC-biased, 60 Hz AC heated filaments near each of these anodes provided preionization both to assist the HeGDC startup between discharges and to provide preionization for the startup of all NSTX plasmas [2-6]. These biased preionization filaments facilitate breakdown of the glow discharge at the actual operating pressure, voltage, and current, thereby greatly simplifying process control [1]. Without them, the GDC required higher voltage and higher pressure for breakdown. In addition, increasing the filament bias and current lowered the minimum achievable stable operating GDC pressure.

Recently, the GDC system was modified to investigate the possibility of achieving more uniform GDC and boronization coverage and increased discharge reliability at lower gas pressure. The fixed anode at Port-L was replaced with a Movable GDC Probe (MGP) anode that can be inserted 1.2 m to about midway between the inner and outer vessel walls. The fixed anode at Port-G was also moved to accommodate a diagnostic installation. The preionization filaments, power supplies, and controls remained the same.

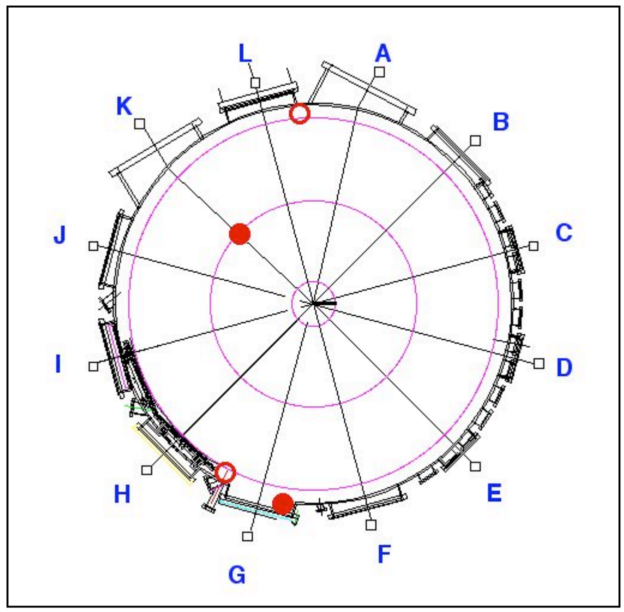

Fig. 1. Schematic diagram showing layout of inital NSTX HeGDC system (1999-2005) [open circles at Ports G and L] and the location of the upgraded HeGDC system anodes [solid circles, Ports G and K] relative to the vessel ports. The MGP is mounted at Port-K; the present fixed GDC anode is at Port-G.

II. MGP TRANSPORT SYSTEM

The MGP anode is moved downward into the vessel at a 22° angle from vertical by means of a Thermionics Northwest Inc. bellows motion drive [7] mounted on a vertical port at the top of NSTX (Fig. 2) employing a 5 cm diameter bellows with a stroke length of 122 cm (Fig. 3). It is supported by brackets from the upper vessel structure and is mounted to the 6-inch Conflat flange of a Torus Interface Valve (TIV). The stroke length from the MGP zero position to a parking position between discharges behind the divertor plasma facing components (PFCs) is 42 cm. The additional stroke length into the main plasma chamber to the operating position is 75 cm.

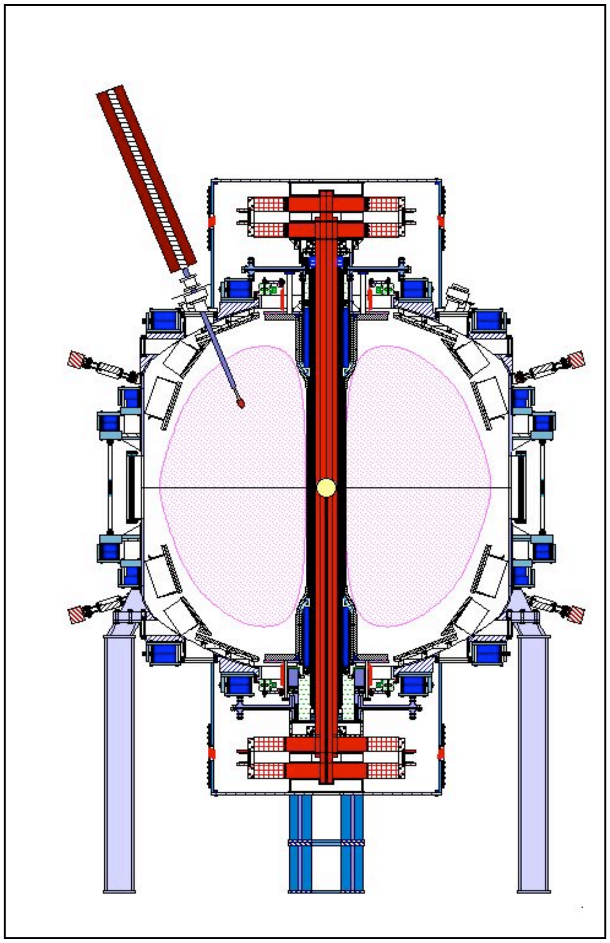

Fig.2. Schematic cross section of NSTX showing the orientation of the MGP for insertion 22° downward 1.2 m into the vessel in 85 s.

III. Design of the Anode Probe

The bellows interior is at NSTX vacuum pressure (Fig. 3). The bellows is supported on its inner-side by a 3.8 cm diameter SS-304 pipe, which is guided by roller bearings and moves with the bellows into the vessel as the bellows is compressed [7]. An electrically isolated, anode-support tube fits inside the bellows guide tube and its interior is at atmospheric pressure. The anode itself is a 4-fin anode (15.2 cm long x 1.27 wide x 0.32 cm thick) welded 90° apart, on a 0.95 cm diameter, SS-304 shaft. The anode-support tube has four functions. It supports the anode tip, connects the electrical bias to the anode, provides a channel for 90 psi instrumentation cooling air to the base of the anode tip, and provides a conduit for two spot welded Type-K thermocouples for measuring the temperature at the anode base. The bare wires of these thermocouples exit the base region via 2-holed ceramic tubing supported by SS-304 tubes. Upon exiting the ceramic tubes, the thermocouple wires are sheathed in woven ceramic cloth fastened to the ceramic tubes with ceramic cement. The

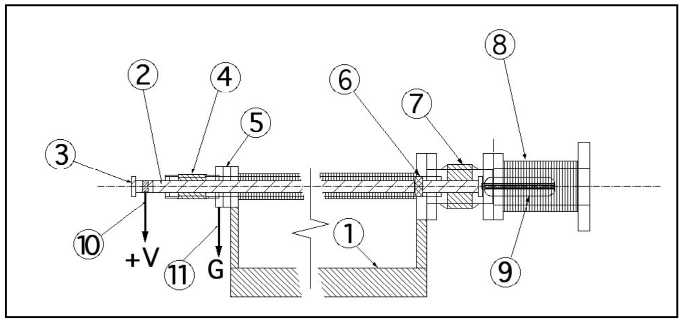

Fig.3. Partial schematic diagram of the assembled MGP showing (1) bellows motion drive, (2) anode support tube whose interior conducts 90 psi air flow to the anode base, (3) port to interior of anode support tube for cooling air and thermocouples (4) ceramic electrical isolation, (5) bellows support tube 2-3/4 inch Conflat Flange, (6) ceramic spacer guide for bellows support tube, (7) ceramic electrical isolation from outer vessel, (8) bellows to provide isolation from vessel bake-out expansion and motions, (9) anode fins, (10) electrical bias connection, (11) ground connection to outer-vessel single-point ground.

anode-tip assembly is welded to the anode-support tube that is centered inside the bellows support tube using a machineable glass ceramic spacer with longitudinal channels to allow for vacuum pumping of the probe interior by the vessel. The entire length of the anode-support tube is clad in woven ceramic cloth to shield it from the glow discharge, and thereby restrict the anode region to the anode-tip. The anode-support tube transitions out of the bellows support tube via a 2-3/4-inch Conflat flange. The anode-support tube is electrically isolated from the bellows motion drive by a vacuum ceramic insulator (Fig.4) The anode-tip typically absorbs ~1500 watts during operation (750 v, 2 A, @ 2mT He) and the anode base operating temperature is in the range from 42- 90°C. This heat is removed via a 0.48 cm ID air-hose directing 90 psi air into the anode-support tube. This air-hose, the electrical bias, and control signal cables are fastened to the traveling flange of the bellows motion drive and need to move in a flexible manner up to 122 cm as the MGP is inserted or

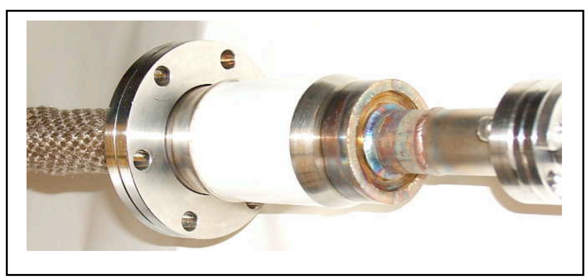

Fig.4. Photo showing the exit end of the anode-support tube. Shown is the 2-3/4-inch Conflat flange that fastens to the bellows support tube Conflat flange, the woven ceramic cloth for glow-discharge shielding, and the welded vacuum ceramic insulator that electrically isolates it from the main bellows motion drive.

retracted from the vessel. A flexible air-hose is coiled around a 15.2 cm OD PVC pipe fastened parallel to the bellows. Similarly the anode bias cable is installed through another flexible air-hose. This flexible air-hose was coiled around a 10.2 cm OD PVC guide pipe. Both PVC guide assembles were mounted to side of the bellows motion drive and parallel to its motion axis.

The MGP design employed standard vacuum compatible materials; stainless steel, alumina, and glass ceramic. The only magnetic material is in the Stepper Motor mounted 178 cm from the port at R= 208 cm, Z= 376 cm. An analysis indicated that its stray field in the plasma region would have no operational effect on the plasma. The estimated typical magnetic forces were 10-13 N, and the support structure easily provided adequate mechanical support against these forces.

IV. Controls Design

The MGP is remotely operated using a hybrid control system involving a commercial stepper motor system [7], hardwired controls, the NSTX Vacuum PLC [8], and central computer system [9]. The control system allows either manual control of probe position and anode voltage or an automatic mode, synchronized with the NSTX shot cycle for automatic insertion, withdrawal, voltage application, and integration with other gas and analysis systems. It has been found most convenient for an operator to initiate the automatic GDC sequence that includes closing window shutters, closing selected torus interface valves, MGP insertion, initiating the glow-discharge for a specified time, and the reverse sequence upon GDC completion. The Vacuum PLC monitors interlocks, controls sequencing, and monitors the glow-discharge parameters. Fig. 5 shows the PLC user interface screen.

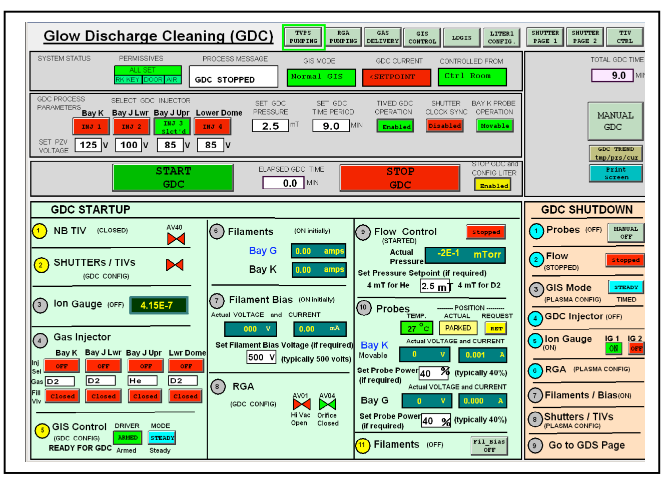

Fig. 5. PLC User Interface screen showing the glow-discharge conditions and allowing for operator changes if needed.

The central computer system uses EPICS software to provide a graphical user interface, interlocks, and control set-point monitoring, communications with the PLC [9]. It also provides communications/control of the bellows motion drive *via* a six-axis stepper motor controller [7].

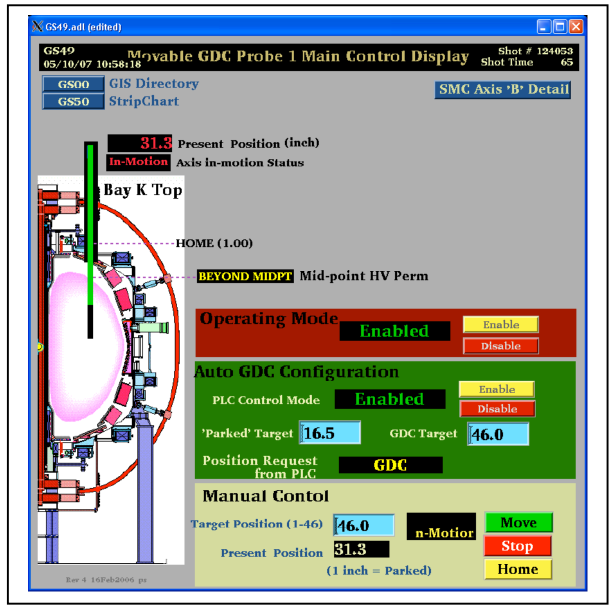

Fig.6. The EPICS User Interface page used by the MGP operator.

Fig.6 shows the EPICS Graphical User Interface used by the MGP operator. The display shows the probe position traversing the parked position (16.5 to 46 inches) to the inserted position, and a selectable EPICS display page for a probe tip temperature strip-chart with a time span of 90 min. Archiving is performed continuously at once-per-minute sampling of the glow-discharge current and voltage and discharge neutral gas pressure gauge. Probe position is also stored. The PLC and EPICS software interlocks and the hardwired controls are configured to provide monitoring and control for MGP motion, status, electrical bias, and the state of the discharge sequence (refer to Table I). The pre-discharge pulse check will stop the NSTX shot cycle if the probe does not fully retract to its parked position behind the graphite PFC's. Wireless www-based video cameras are used to monitor MGP motion. Tests have been performed to determine the limits of the MGP motion interlocks. It was found that the probe drive has been generally reliable.

Table I. MGP Stroke Distances, Rates, and Durations.

Sequence	Unit
• Adopted Bellows Travel Rate (116.8 cm/90 s)	1.3 cm/s
• Distance from MGP Zero to Park Between Shots	42 cm
• Distance from Park to Operation Point	75 cm
• Stroke Time from Park to Operation Point	58 s
• GDC Process Start Time to Probe Bias ON	40 s
• GDC Process Stop Time to Ready for Plasma	75 s

V. Performance Results

The MGP was evaluated by performing high performance NSTX deuterium plasmas with HeGDC applied between discharges. It was found that the MGP

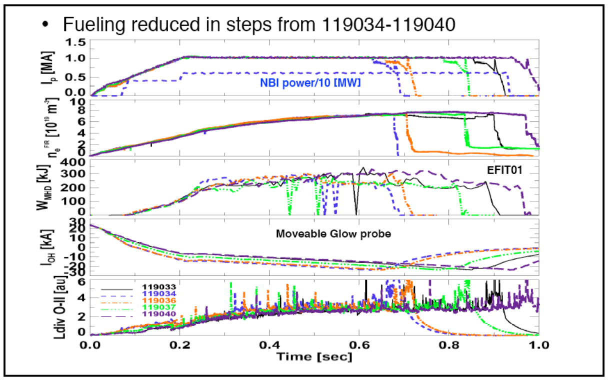

Fig.7. Reproducible long pulse discharges achieved with 6.5 min HeGDC between discharges.

allowed a reduction of the NSTX shot cycle (Fig.7) from about 15-17.5 min (9-11.5 min HeGDC) down to about 10-12.5 min. (4-6.5 min. HeGDC). MGP application at 2, 3, and 4 mTorr with 7 min HeGDC found that the subsequent discharge performance was insensitive to the GDC pressure. In a comparison of the MGP with the fixed wall probes, it was found that performance was similar in preparing wall conditions for individual long pulse discharges, in that each allowed 1 MA, 1 sec long pulses in double null diverted (DND) configuration with similar plasma stored energy. In addition, the MGP has proved reliable in facilitating many experiments, *e.g*. to confirm that the plasma shape must be close to DND or biased slightly downward to facilitate H-mode access (Fig.8).

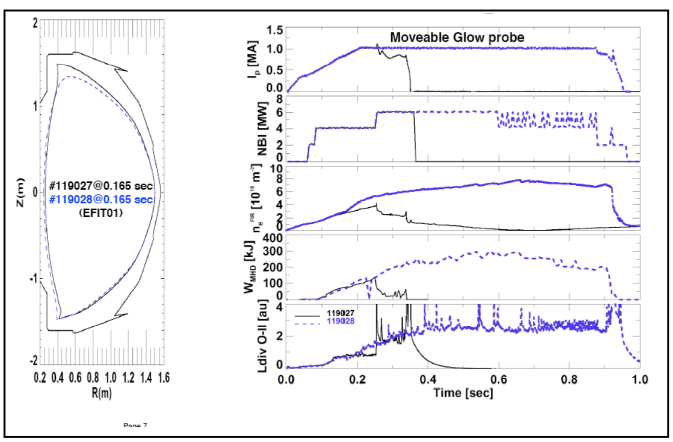

Fig.8. H-mode access easier as lower X-point becomes more dominant due to improved wall conditioning.

VI. CONCLUSIONS

The MGP design has been used unchanged as described in this paper between every discharge during last two NSTX experimental campaigns. It has also been used to apply boronization. Its performance has been reliable in the EMI noise of the NSTX environment. The MGP has improved NSTX performance and enabled a faster discharge repetition rate.

Recently, HeGDC has been applied in NSTX while lithium was being evaporated from an oven mounted at the top of the vacuum vessel through an opening in the upper divertor plate onto the lower region of NSTX. The HeGDC ionized the lithium plume causing some of it to be deposited on more distant regions of the vessel surfaces and resulting in a global "lithiumization" of the PFCs. The effects of this on discharge performance are now being investigated.

ACKNOWLEDGMENTS

We acknowledge the technical contributions of R. Delaney, S. Gifford, J. Desandro, J. Kukon, S. Jurczynski, S. Vinson, and J. Winston. Work Supported by USDOE Contract No. DE-AC02-76-CHO3073

REFERENCES

[1] H. W. Kugel, et al., "NSTX Filament Preionization and Glow Discharge Cleaning Systems", Proc. of the IEEE/NPSS 18 th Symposium On Fusion Engineering, Albuquerque, NM, October 25-29, 1999, p296 (IEEE 99CH37050).

[2] H. W. Kugel, "Overview of Impurity Control and Wall Conditioning in NSTX", J. Nucl. Mater. 290-293 (2001)1185-1189.

[3] C. H. Skinner, *et al*., "Effect of Boronization on Ohmic Plasmas in NSTX", Nucl. Fusion **42** (2002) 329.

[4] W. Blanchard, *et al*., "Boronization on NSTX using Deuterated Trimethylboron", Proceedings of the IEEE/NPSS 19 th Symposium on Fusion Engineering in Atlantic City, NJ, January 21-25, 2002 (IEEE 02CH3723).

[5] H. W. Kugel, *et al*., "Impact of the Wall Conditioning Program on Plasma Performance in NSTX" , J. Nucl. Mater. **313-316** (2003) 187.

[6] H.W. Kugel, et al., "Development of NSTX Particle Control Techniques", J. Nucl. Mater., **337-339** (2005) 495.

[7] 122 cm Bellows Motion Drive, Thermionics Northwest, Inc, 231-B Otto Street, Port Townsend, WA 98368 USA.

[8] Allen Bradley, Inc., Model PLC-5 with RSVIEW-32,Graphical User Interface, Rockwell Software Inc.

[9] P. Sichta, et al, "Status of the Experimental Physics and Industrial Control System at NSTX", Proc. of the IEEE/NPSS 19th Symposium on Fusion Engineering, Atlantic City NJ, January 22-25, 2002 (IEEE 02CH3723).

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