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| **Princeton Plasma Physics Laboratory**  **NSTX Experimental Proposal** | | | |
| Title: **Effect of externally applied 3-D field on divertor profiles** | | | |
| **OP-XP-1046** | Revision: **1.0** | Effective Date:  *(Approval date unless otherwise stipulated)*  Expiration Date:  *(2 yrs. unless otherwise stipulated)* | |
| **PROPOSAL APPROVALS** | | | |
| **Responsible Author: J-W. Ahn** | | | Date **6/30/10** |
| **ATI – ET Group Leader: V. Soukhanivskii** | | | Date |
| **RLM - Run Coordinator: E. Fredrickson** | | | Date |
| **Responsible Division: Experimental Research Operations** | | | |
| **RESTRICTIONS or MINOR MODIFICATIONS**  (Approved by Experimental Research Operations) | | | |
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NSTX EXPERIMENTAL PROPOSAL

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| TITLE: **Effect of externally applied 3-D field on divertor profiles** | No. **OP-XP-1046** |
| AUTHORS: **J-W. Ahn, J.M. Canik, R. Maingi, T.K. Gray, A. Loarte, A.G. McLean, J.-K. Park, O. Schmidtz, andV. Soukhanovskii** | DATE: **6/30/10** |

# 1. Overview of planned experiment

The purpose of this experiment is to investigate the effect of externally applied 3-D magnetic perturbation on the divertor heat and particle flux profiles in various plasma conditions. We have observed clear strike point splitting from the measured IR heat flux and Dα particle flux profiles and compared it with vacuum field line modeling to find an excellent agreement. Experiment in FY10 will focus on the scan of major parameters of interest as follows: 1) Pedestal collisionality is a parameter identified to play an important role in forming striations in the heat flux profiles in other tokamaks such as DIII-D. We can achieve a wide collisionality scan using the continuous density ramp-up in the Li-enhanced ELM-free H-mode plasmas. 2) On the other hand, q95 is a parameter that can play a role in determining how big the contribution of resonant component of the applied 3-D field is to the divertor profile modification. We plan to take two q95 points, ie q95~6 and q95~11 by changing Ip (1.2MA and 0.8MA) at constant Bt (=0.5T). 3) Ip scan at constant q95 is also planned to be executed because this could help separate the SOL plasma change from the pedestal plasma change (narrower SOL width with higher Ip), and therefore could be used to investigate if strike point splitting is solely affected by the stochastic B-field region in the pedestal area or the SOL plasma also plays a role. 4) Also, it is not clear if the formation of strike point splitting is affected by shape parameter, ie triangularity and elongation, etc. We will therefore apply n=3 perturbation fields to a low triangularity plasma (δ~0.6) to see if the striation is observed at the divertor surface. 5) The last important issue to be addressed is the possibility of toroidally asymmetric heat and particle flux deposition caused by the 3-D field application. This issue can be investigated by rotating the applied 3-D field toroidally and see if this causes change in the measured profiles. We plan to rotate the 3-D field at two frequencies at 40Hz and 100Hz.

# 2. Theoretical/ empirical justification

Tokamaks are commonly regarded to have toroidally axisymmetric magnetic configuration. Therefore, plasma facing components (PFCs) are also designed and built axisymmetric to protect areas where high heat and particle fluxes are expected from the 2D equilibrium. However, the application of small, non-axisymmetric magnetic field perturbations produced by internal or external coils has been recently found to modify and break the axisymmetry of divertor profiles as well as to have significant impact on the plasma performance in tokamaks. As the present plan for the International Thermonuclear Experimental Reactor (ITER) relies on the use of 3-D magnetic perturbation for the Edge Localized Mode (ELM) suppression, the effect of these 3-D fields on the heat and particle footprints on the divertor plates is of substantial interest.

In DIII-D, large type-I ELMs have been successfully eliminated by applying resonant magnetic perturbations (RMPs) produced by a series of coils inside the vacuum vessel (internal or “I-coils”). In the National Spherical Torus Experiment (NSTX), long ELM-free H-mode plasmas were achieved by heavy lithium evaporation and coating onto the plasma facing components. Application of 3-D fields to these plasmas triggered ELMs with the ELM frequency controlled by the frequency of applied 3-D field coil currents. When the external 3-D field is applied, modification of the magnetic equilibrium produces a 3-D structure of perturbed magnetic field lines in the plasma edge, where the poloidal magnetic flux is re-organized into topological structures known as homoclinic tangles. Perturbed by non-axisymmetric 3-D fields, the separatrix is split into multiple invariant manifolds forming a 3-D lobe structure for the open field lines, which are a mixture of long connection length stochastic field lines and short connection length laminar field lines. The lobe structure of the open field lines generates a striated, *ie* split, strike point (SP) pattern radially across the divertor target surface. This structure is expected to be reflected in the measured divertor heat and particle flux profiles and such an observation during the 3-D perturbation field application was recently reported in DIII-D and NSTX H-mode plasmas.

# 3. Experimental run plan

The experiment will be carried out with long pulse ELM-free H-mode plasmas by applying a modulated coil current for n=1 and n=3 perturbations. The amplitude of the coil current will be below the ELM triggering threshold, ie I3-D=500A for 135184 (n=3). The duration of magnetic perturbation will be kept as short (~35ms) as it does not cause significant change in core plasma parameters such as toroidal velocity and pedestal profiles. The parameter scan (Ip, Bt, and PNBI) will focus on taking end points, ie Ip=0.8MA and 1.2MA, Bt=0.33T and 0.5T, PNBI =3MW and 5MW. After completing this 8-shot matrix, we will move on to cover low δ plasma (reference shot: 137605). Finally, a toroidally rotating n=1 perturbation field will be applied to investigate if asymmetric heat and particle deposition is caused by the applied 3-D field.

1. Establish reference shot (135184, Ip=0.8MA) but with Bt=0.5T and PNBI =3MW, and then apply n=3 field (freq=10Hz, duration=35ms), ***1 shot***
2. q95 and Ip scan: shot matrix for Bt=0.33T and 0.5T, Ip=0.8MA and1.2MA, ***4 shots***

(Bt, Ip) = (0.33T, 0.8MA) (0.33T, 1.2MA)

(0.50T, 0.8MA) (0.50T, 1.2MA)

1. Power scan: repeat above at PNBI =5MW, ***4 shots***
2. Application of toroidally rotating n=1 field to the reference discharge above:

Rotation frequency of 10Hz and 100Hz, ***2 shots***

1. Establish a low δ discharge (137605)
2. Apply n=3 perturbation field: constant coil current of 1kA to maximize possibility of strike point splitting, ***2 shots***
3. Total number of good shots: ***~12 shots***

# 4. Required machine, NBI, RF, CHI and diagnostic capabilities

All NBI sources A, B, and C are necessary to heat the plasma up to 5MW. LITER and LLD will be needed to produce ELM-free H-mode plasmas. SPA coils are required to apply n=1 and n=3 perturbation fields. Capability of toroidally rotating n=1 fields is also essential. The newly installed dense LP array will be very helpful to evaluate the particle flux profile modification, particularly for low-δ discharges. Accurate rtEFIT control is necessary to produce these low-δ discharges with the outer divertor leg at the desired location on the outer divertor surface.

# 5. Planned analysis

2-color IR camera data will be analyzed to calculate heat flux profiles. Dα camera data will be used as a proxy to the particle flux data. The wide-angle LLD camera viewing lower divertor tiles from the top of the machine will be also analyzed for the analysis of striation structure. Vacuum field line tracing (J.M. Canik) as well as IPEC (J.-K. Park) calculations will be carried out to compare the measured heat and particle flux profiles with modeled B-field structure. PEST calculation could be helpful to look into how well rational surface locations are aligned with the peaks in the applied perturbation.

# 6. Planned publication of results

The results will be presented at the 2010 APS DPP invited talk as well as in the 2010 IAEA Fusion Energy Conference. Both meetings offer opportunity to submit papers (PoP and NF, respectively), therefore clearly demonstrated data are expected to be published in these journals.

PHYSICS OPERATIONS REQUEST

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| **Brief description of the most important operational plasma conditions required:**  - RWM coils configured for *n* = 1, 3 operation  - LITER required  - LLD desired for density (collisionality) control if available  - NBI beam power up to 5MW |
| **Previous shot(s) which can be repeated: 135184 (high delta shot)**  **Previous shot(s) which can be modified: 137605 (low delta shot)** |
| **Machine conditions** *(specify ranges as appropriate, strike out inapplicable cases)*  ITF (kA): **50-60** Flattop start/stop (s):  IP (MA): **0.8 – 1.2** Flattop start/stop (s):  Configuration: **LSN**  Equilibrium Control: **Outer gap / Isoflux** (rtEFIT) **/ Strike-point control** (rtEFIT)  Outer gap (m): **0.08-0.11** Inner gap (m):0.04Z position (m):  Elongation: **2.2 – 2.4** Triangularity (U/L): **0.6-0.8** OSP radius (m): **0.35, 0.68m**  Gas Species: **D** Injector(s):  **NBI** Species: **D** Voltage (kV) **A: 90 B: 90 C:** 80-90 Duration (s): **~ 1.3**  **ICRF** Power (MW): Phase between straps (°): Duration (s):  **CHI**: **Off / On** Bank capacitance (mF):  **LITERs: Off / On** Total deposition rate (mg/min): **30**  **LLD:** Temperature (°C): **optimal for density pumping**  **EFC coils: Off/On** Configuration: **Odd / Even / Other** *(attach detailed sheet)* |

DIAGNOSTIC CHECKLIST

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*Note special diagnostic requirements in Sec. 4*

| **Diagnostic** | **Need** | **Want** |
| --- | --- | --- |
| Beam Emission Spectroscopy |  |  |
| Bolometer – divertor | **X** |  |
| Bolometer – midplane array | **X** |  |
| CHERS – poloidal |  | **X** |
| CHERS – toroidal | **X** |  |
| Dust detector |  | **X** |
| Edge deposition monitors |  |  |
| Edge neutral density diag. |  | **X** |
| Edge pressure gauges |  | **X** |
| Edge rotation diagnostic |  | **X** |
| Fast cameras – divertor/LLD | **X** |  |
| Fast ion D\_alpha - FIDA |  | **X** |
| Fast lost ion probes - IFLIP |  | **X** |
| Fast lost ion probes - SFLIP |  | **X** |
| Filterscopes |  | **X** |
| FIReTIP | **X** |  |
| Gas puff imaging – divertor |  | **X** |
| Gas puff imaging – midplane |  | **X** |
| H camera - 1D |  | **X** |
| High-k scattering |  | **X** |
| Infrared cameras |  | **X** |
| Interferometer - 1 mm |  | **X** |
| Langmuir probes – divertor |  | **X** |
| Langmuir probes – LLD |  | **X** |
| Langmuir probes – bias tile |  | **X** |
| Langmuir probes – RF ant. |  |  |
| Magnetics – B coils | **√** |  |
| Magnetics – Diamagnetism | **X** |  |
| Magnetics – Flux loops | **√** |  |
| Magnetics – Locked modes | **X** |  |
| Magnetics – Rogowski coils | **√** |  |
| Magnetics – Halo currents |  | **X** |
| Magnetics – RWM sensors | **X** |  |
| Mirnov coils – high f. |  | **X** |
| Mirnov coils – poloidal array |  | **X** |
| Mirnov coils – toroidal array | **X** |  |
| Mirnov coils – 3-axis proto. |  |  |

*Note special diagnostic requirements in Sec. 4*

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| **Diagnostic** | **Need** | **Want** |
| MSE |  | **X** |
| NPA – E||B scanning |  | **X** |
| NPA – solid state |  | **X** |
| Neutron detectors |  | **X** |
| Plasma TV |  | **X** |
| Reflectometer – 65GHz |  | **X** |
| Reflectometer – correlation |  | **X** |
| Reflectometer – FM/CW |  | **X** |
| Reflectometer – fixed f |  | **X** |
| Reflectometer – SOL |  | **X** |
| RF edge probes |  |  |
| Spectrometer – divertor |  |  |
| Spectrometer – SPRED |  | **X** |
| Spectrometer – VIPS |  | **X** |
| Spectrometer – LOWEUS |  | **X** |
| Spectrometer – XEUS |  | **X** |
| SWIFT – 2D flow |  |  |
| Thomson scattering | **X** |  |
| Ultrasoft X-ray – pol. arrays |  | **X** |
| Ultrasoft X-rays – bicolor |  | **X** |
| Ultrasoft X-rays – TG spectr. |  | **X** |
| Visible bremsstrahlung det. |  | **X** |
| X-ray crystal spectrom. - H |  | **X** |
| X-ray crystal spectrom. - V |  | **X** |
| X-ray tang. pinhole camera |  | **X** |