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| **Princeton Plasma Physics Laboratory**  **NSTX Experimental Proposal** | | | |
| Title: **Effect of 3-D fields on edge power/particle fluxes between and during ELMs** | | | |
| **OP-XP-1026** | Revision: **1.0** | Effective Date:  *(Approval date unless otherwise stipulated)*  Expiration Date:  *(2 yrs. unless otherwise stipulated)* | |
| **PROPOSAL APPROVALS** | | | |
| **Responsible Author: A. Loarte** | | | Date **8/24/10** |
| **ATI – ET Group Leader: V. Soukhanovskii** | | | Date **8/24/10** |
| **RLM - Run Coordinator: E. Fredrickson** | | | Date **8/24/10** |
| **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 3-D fields on edge power/particle fluxes between and during ELMs** | No. **OP-XP-1026** |
| AUTHORS: **A. Loarte, J-W. Ahn, J.M. Canik, R. Maingi, and J.-K. Park** | DATE: **8/24/10** |

# 1. Overview of planned experiment

This XP aims to investigate the effect of 3-D fields (primarily n=3) on the divertor heat and particle flux profiles during and between ELMs. To see the impact of 3-D fields, we will try to find the best field line alignment with the resonant n=3 components, as it is often observed that good alignment brings most significant changes to the edge plasma characteristics such as ELM suppression and density pump-out. It is expected theoretically that low q95 discharges in NSTX would produce discharges close to that condition and it will be attempted to achieve this condition in XP-1048 (J.-K. Park), which will be used as a base discharge in this XP. We will then perform various parameter scans at this alignment; 1) Ip scan at constant q95, 2) pedestal and SOL plasma collisionality scan, and 3) coil current amplitude scan. Constant q95 for the Ip scan can be maintained by adjusting Bt. Pedestal collisionality can be varied by making use of the pedestal density rise during the H-mode density ramp-up period as well as by changing the pedestal temperature by changing the neutral beam power. The SOL plasma collisionality can be varied by divertor gas puffing. This technique has been proved useful in changing the divertor plasma condition (eg, from sheath-limited to conduction-limited regime in the lithium-enhanced H-mode plasmas in NSTX). Lastly, higher coil current tends to produce more frequent ELMs and we need to investigate the impact of smaller ELMs on the divertor profiles at similar pedestal pressure and divertor conditions, which can be accomplished by scanning the coil current.

# 2. Theoretical/ empirical justification

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. It is not yet clear how the applied 3-D fields trigger ELMs in the presence of strong lithium surface conditioning. It has been observed that the 3-D field application produces a flat pressure profile area in the pedestal region, presumably due to the magnetic island generation, and this relaxes the pedestal pressure profile as a whole. The relaxation of pedestal profile is generally known to suppress ELMs and the reason why the ELMs are triggered instead is still under investigation. 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. An important result from the previous data in NSTX regarding the heat flux deposition between and during the ELMs is that the heat flux appears to largely follow the structure of the applied 3-D fields in both cases. This result needs to be confirmed in a wide range of plasma parameters. Also, ELM control in ITER is required for a large range of plasma conditions, not only for the period of flat top of 15 MA scenario. Dependences of the applied 3-D field effects on the divertor power/particle fluxes on plasma parameters, both for during the ELM and inter-ELM periods, are needed to be determined to understand consequences for ITER. Compatibility with other scenario requirements also needs to be checked such as the acceptable stationary power flux and erosion levels, etc. The purpose of this experiment is the characterization of 3-D field effect above the ELM triggering threshold with various parameter scans (eg, Ip, *ν\*e*, q95 , and , I3-D scan, etc).

# 3. Experimental run plan

A modulated coil current for n=3 perturbations will be applied to long pulse ELM-free H-mode plasmas. The amplitude of the coil current will be above the ELM triggering threshold, which will have been determined from the result of XP-1046. The threshold is expected to be something like I3-D=500A for n=3 fields. The duration of magnetic perturbation will be kept as short (~35ms) as the plasma would have enough time to recover after triggering an ELM.

1. Establish reference shot (140000, a lowest q95 discharge from J.-K. Park’s XP-1048) ELM-free discharge with lithium=300mg

***1 shot***

1. Coil current scan (In=3~ 1000A, 1500A, 2000A, t n=3=300ms, constant amplitude)

***3 shots***

1. Ip scan at constant q95: Keep q95 at the lowest value, ie q95=6-7, In=3=1100A

(Ip, Bt)=(700kA, 0.35T)

(900kA, 0.45T)

(1100kA, 0.55T)

***3 shots***

1. SOL plasma collisionality scan: Add two more divertor D2 gas levels, making the total number of divertor conditions three, to the reference discharge. Take two good shots for each divertor condition. Take shots with higher D2 gas puffing level (~3000 Torr of Bay E GIS) to obtain highest divertor density and lowest temperature, and then take ones with lower gas level (~1500 Torr of Bay E GIS). Coil current In=3~ 1100A, Ip=700kA

***4 shots***

1. Pedestal plasma collisionality scan: Apply modulated n=3 coil current at three time slices (t=300ms, 500ms, and 700ms) during the H-mode density ramp-up period in order to apply n=3 fields at different pedestal density levels during the discharge. In addition, apply two different NBI power levels (PNBI=2MW and 6MW) to change the pedestal electron temperature. Along with the three density levels, this will ultimately lead to a total of 6 pedestal collisionality levels to be scanned. Ip and q95 levels are to be identified in the step # (3), in the way that we can achieve the lowest q95 (and highest Ip).

***2 shots***

1. Coil current alignment scan: Misalign 3-D field coil spectrum by changing q95 by 3, ie shots with q95=9 and 12 based on the lowest q95 (~6) that will have been taken in step #3. Change of q95 is to be performed by the change of Bt with fixed Ip=700kA, ie Bt=0.45 and 0.55T. In=3=1100A to make sure ELMs are triggered.

***2 shots***

1. Total number of shots: ***15 good 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 6MW. LITER and LLD will be needed to produce ELM-free H-mode plasmas. SPA coils are required to apply n=3 perturbation fields. Accurate rtEFIT control is necessary to generate reproducible plasmas.

# 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* = 3 operation  - LITER required  - LLD desired for density (collisionality) control if available  - NBI beam power up to 6MW | | |
| **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** |