Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: **"Snowflake" divertor in NSTX**		
OP-XP-924	Revision:	Effective Date: **07/23/2009** *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS	
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ATI – ET Group Leader: V. A. Soukhanovskii / R. Maingi	Date 07/23/2009
RLM - Run Coordinator: R. Raman	Date 07/23/2009
Responsible Division: Experimental Research Operations	
Chit Review Board (designated by Run Coordinator)	

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: "Snowflake" divertor configuration in NSTX — No. **OP-XP-924**

AUTHORS: V. A. Soukhanovskii — DATE: **07/23/2009**

1. Overview of planned experiment

The goal of the experiment is to obtain and study the "snowflake" divertor (SFD) configuration in NSTX. In the first part, configuration scoping studies will be performed to obtain the SFD configuration 1) using the developed strike point PCS control; 2) using pre-programmed divertor coil currents. Once stable SND configurations are obtained, we will characterize their stability properties and divertor performance in the second part of the XP. It is expected that this XP will provide data and lead to future XPs where the NSTX PCS will be further used to control the divertor "snowflake" configuration.

2. Theoretical/ empirical justification

The "snowflake" divertor concept has been recently proposed by Dr. D. D. Ryutov [1-5]. The concept has been evaluated using analytic and numerical modeling [1-5], and first results have been obtained in the TCV tokamak [6]. In the "snowflake" divertor configuration, a second-order null is created in the divertor region by placing two X-points in close proximity to each other. This configuration has been theoretically shown to have higher divertor flux expansion and different edge turbulence and magnetic shear properties, beneficial for divertor heat flux reduction, and possible "control" of turbulence and ELMs. In NSTX, two divertor coils PF1A and PF2L will be used to obtain the "snowflake" configuration (Figure 1).

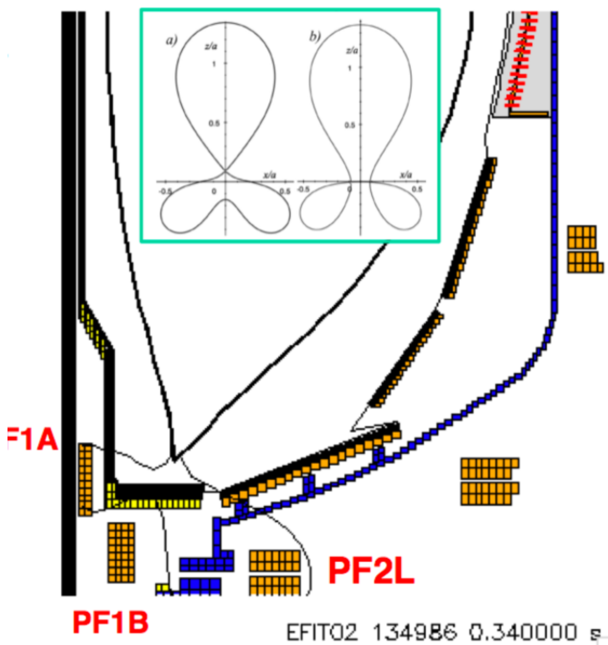


Figure 1 Implementation of the "snowflake" divertorr configuration in NSTX using the PF1A and PF2L coils.

Numerous ISOLVER codes runs identified general directions for this XP. One approach is to take advantage of the XP 904 medium triangularity discharges and the developed plasma control system (PCS) algorithm for the inner and outer strike point control. This way, the inner strike point will be at the nearly constant R, Z, and R, Z of the outer strike point will be varied, while maintaining the shaping parameters, such as the triangularity and squareness, nearly constant. Another approach is to start from a standard fiducial discharge, which is a lower single null configuration with PF1A coil only, and add PF2L pre-programmed current in the flat-top in small (1-2 kA) increments. Examples of transiently obtained "snowflake" configuration in NSTX with the corresponding divertor coil current wave forms, as well as the ISOLVER code modeling for the second approach are shown in Figure 2.

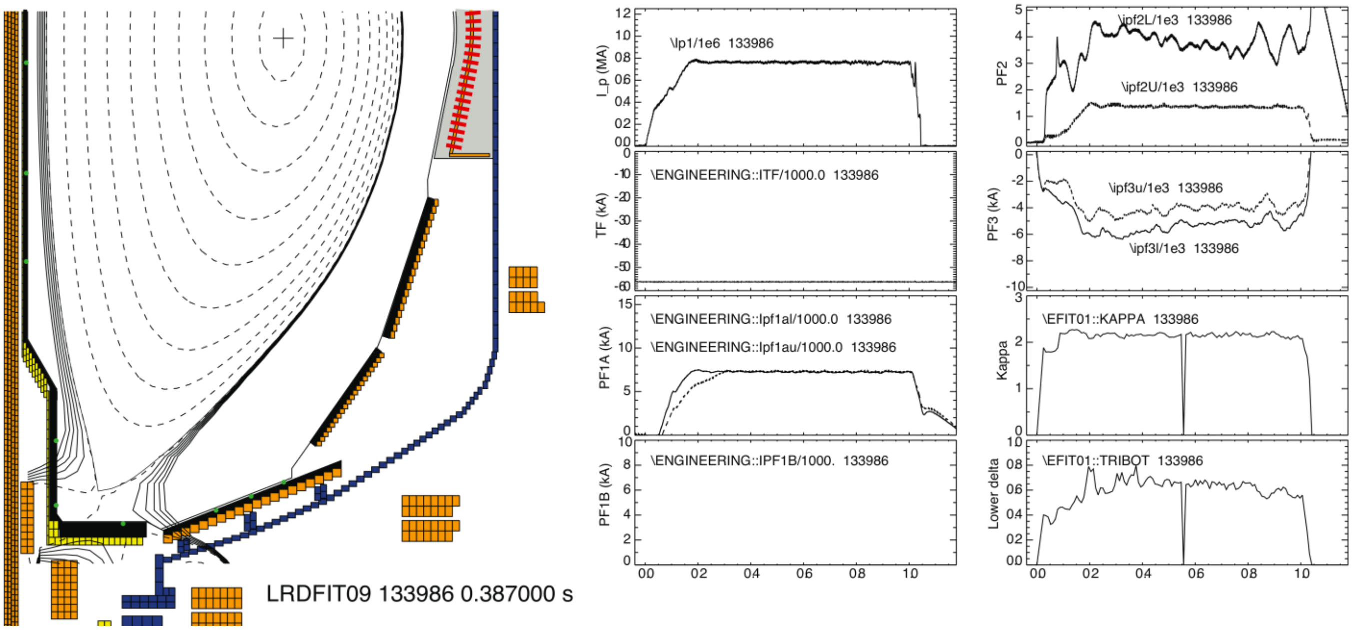
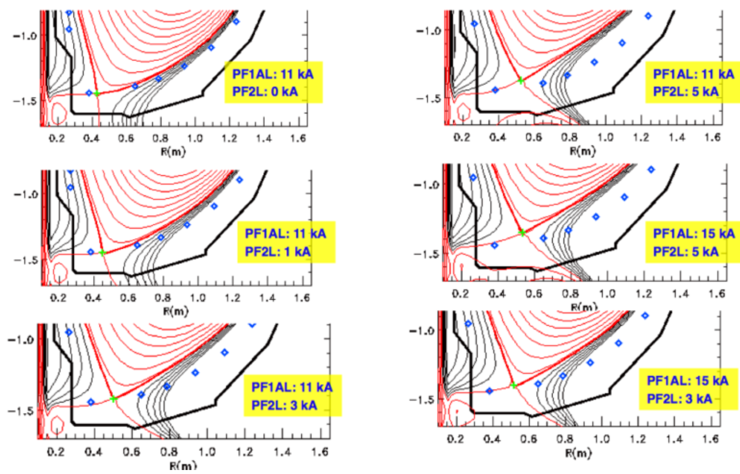


Figure 2. Example of transiently obtained "snowflake" configuration, the corresponding divertor coil currents, and the configuration trend modeling using ISOLVER code



Finally, we note that from ISOLVER modeling, all "snowflake"-like configurations in NSTX had medium triangularity in the range 0.45-0.6. This configuration often has the outer strike point near or in the region where the liquid lithium divertor module LLD-I will be installed. It is therefore of great interest to study SOL and divertor transport and turbulence properties in the "snowflake" configuration, so that in the future, the potential synergy with LLD can be explored.

3. Experimental run plan

3.1 Obtain SFD configuration using PCS strike point control algorithm developed in XP 904

- Reproduce discharge 133986 (800 kA, 4-6 MW NBI) or 134986 (900 kA, 4-6 MW NBI)
- Keep the inner strike point at R=0.279 m (CS), Z=-1.465 m
- Scan the outer strike point
  - from R=0.44 to 0.55 m at Z=-1.602 m (horizontal plate). Use the following values for the OSP controller: R = 0.440, 0.480; 0.520; 0.550 m
  - from R=0.69 to 0.73 m (tilted plate). Use the following values for the OSP controller: R = 0.69; 0.71; 0.73 m
- Reproduce configuration with closest lower X-points from the above shots

3.2 (Optional) Obtain SFD configuration from a fiducial

- Use the latest fiducial, or shot 134984 (900 kA, 4-6 MW NBI)
- Starting from a flat-top time point, e.g. 0.24 s, start varying PF2L current
  - PF2L current was 0 kA. Vary it within 1-7 kA (0.00125 to 0.00875 normalized to I_p) in increments of 1 kA. Stop when the outer strike point approached the CHI gap.
- PF1A current was 11.5 kA. Vary it within 4-12 kA (0.005 to 0.015 normalized to I_p) to optimize for the “snowflake” configuration.
- Obtain a discharge with a standard divertor configuration and the same shaping parameters (lower and upper triangularity, elongation) for comparison – adjust PF1A and PF2L currents accordingly.

3.3 SFD configurations characterization (time-permitting)

- Use the best SFD discharge from above, adjust outer gap to 10 cm for best pedestal profile measurements
- Vary NBI power between 2 and 6 MW
- Vary plasma current in the range 0.7-1.2 MA

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

Three NBI sources at 90 kV will be needed. RF and CHI will not be needed.
Physics Operations Request and Diagnostic Checklist are attached.

5. Planned analysis

Magnetic equilibria will be analyzed with LRDFIT. TRANSP and UEDGE analysis will be also performed. BFIT runs for pedestal parameters and stability calculations may also be desirable.

6. Planned publication of results

The results will be presented at the PSI and IAEA FEC meetings in 2010 and published in refereed journals as appropriate.

References:

[1] M.V. Umansky, R.H. Bulmer, R.H. Cohen, T.D. Rognlien and D.D. Ryutov, Analysis of geometric variations in high-power tokamak divertors, Nucl. Fusion 49 (2009) 075005

[2] D.D. Ryutov, R.H. Bulmer, R.H. Cohen, D.N. Hill, L. Lao, J.E. Menard, T.W. Petrie, L.D. Pearlstein, T.D. Rognlien, P.B. Snyder, V. Soukhanovskii, M.V. Umansky, A Snowflake Divertor: a Possible Way of Improving the Power Handling in Future Fusion Facilities, Paper IC/P4-8, 22st IAEA Fusion Energy Conference, Geneva, Switzerland, 10/2008.

[3] Ryutov, D.D., Cohen, R.H.; Rognlien, T.D.; Umansky, M.V., The magnetic field structure of a snowflake divertor, Physics of Plasmas, v 15, n 9, p 092501 (13 pp.), Sept. 2008

[4] D.D. Ryutov, A “SNOWFLAKE” DIVERTOR AND ITS PROPERTIES, 34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.31F, D-1.002 (2007)

[5] Ryutov, D.D. , Geometrical properties of a "snowflake" divertor, Physics of Plasmas, v 14, n 6, p 64502/1-4, June 2007

[6] F Piras, S Coda, I Furno, J-M Moret, R A Pitts, O Sauter, B Tal, G Turri, A Bencze, B P Duval, F Felici, A Pochelon and C Zucca, Snowflake divertor plasmas on TCV, Plasma Phys. Control. Fusion 51 (2009) 055009

PHYSICS OPERATIONS REQUEST

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(use additional sheets and attach waveform diagrams if necessary)

Describe briefly the most important plasma conditions required for the experiment:

Previous shot(s) which can be repeated: 133986, 134986

Previous shot(s) which can be modified: 133986, 134986

Machine conditions *(specify ranges as appropriate, strike out inapplicable cases)*

I_{TF} (kA): -56.2 Flattop start/stop (s):

I_P (MA): 0.8-0.9 Flattop start/stop (s):

Configuration: **LSN – "Snowflake" (two X-points)**

Equilibrium Control: **1) ISP and OSP PCS control; 2) Outer gap / Isoflux** (rtEFIT)

Outer gap (m): **10-12 cm** Inner gap (m): **3-6 cm** Z position (m): **0.0**

Elongation κ: 2.15-2.20 Upper/lower triangularity δ: 0.50-0.65

Gas Species: $\mathbf{D_2}$ Injector(s): LFS # 2 and CS

NBI Species: **D** Voltage (kV) **A: 90** **B: 90** **C:** 90 Duration (s): 1 s

A: 0.040 - 1.0 s, B: 0.080 – 1.0 s, C: 0.110 –0.2 (1.0) s

ICRF Power (MW): None Phase between straps (°): Duration (s):

CHI: **Off** Bank capacitance (mF):

LITERs: On Total deposition rate (mg/min): **5-10**

EFC coils: Off Configuration: **Odd / Even / Other** *(attach detailed sheet*

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Bolometer – tangential array	√	
Bolometer – divertor	√	
CHERS – toroidal	√	
CHERS – poloidal	√	
Divertor fast camera	√	
Dust detector		
EBW radiometers		
Edge deposition monitors		
Edge neutral density diag.		
Edge pressure gauges	√	
Edge rotation diagnostic	√	
Fast ion D_alpha - FIDA		
Fast lost ion probes - IFLIP		
Fast lost ion probes - SFLIP		
Filterscopes	√	
FIReTIP		√
Gas puff imaging	√	
Hα camera - 1D	√	
High-k scattering		
Infrared cameras	√	
Interferometer - 1 mm		
Langmuir probes – divertor	√	
Langmuir probes – BEaP		
Langmuir probes – RF ant.		
Magnetics – Diamagnetism		
Magnetics – Flux loops	√	
Magnetics – Locked modes		
Magnetics – Pickup coils	√	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents		
Magnetics – RWM sensors		
Mirnov coils – high f.		
Mirnov coils – poloidal array		√
Mirnov coils – toroidal array		√
Mirnov coils – 3-axis proto.		√

Note special diagnostic requirements in Sec. 4

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