Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Fueling NSTX plasmas with Supersonic Gas Jet

OP-XP-???	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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ATI – ET Group Leader:	Date
RLM - Run Coordinator: J. Menard, S. Sabbagh (Deputy)	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

1. Overview of planned experiment

Supersonic gas injector (SGI) has been developed and commissioned on NSTX in FY04. The experiment will study fueling characteristics of the SGI, and the compatibility of the supersonic gas jet fueling with high performance plasma regimes. In the first part of the experiment, the SGI fueling efficiency and edge plasma characteristics will be evaluated for a reproducible injection of the supersonic deuterium jet in an ohmic L-mode plasma, the LCFS – nozzle distance will be varied, and the SGI will be used for plasma start-up development. In the second part of the experiment, supersonic D_2 injections will be performed in an H-mode plasma (ELM-free and ELMy), in an HHFW-heated plasma. The latter part of the experiment may be done on different days. The outcome of the second part will be the fueling efficiency and gas jet penetration measurements in H-mode plasmas, and an initial evaluation of the ELM control potential of the SGI. It is planned to model the results of the experiment with the edge fluid code UEDGE and the neutral transport MC code DEGAS 2.

2. Theoretical/ empirical justification

A new method for re-fueling a high temperature fusion plasma with a supersonic gas jet has been developed on the HL-1M tokamak [1] and later implemented on several nuclear fusion plasma facilities [2, 3]. The method favorably compares to the conventionally used fueling methods: subsonic gas injection at the plasma edge, and high velocity cryogenic fuel pellet injection into the plasma core. Experiments have demonstrated a fueling efficiency of 0.3 - 0.6, reduced interaction of injected gas with in-vessel components, and therefore a higher wall saturation limit. Several models have been used to explain the enhanced penetration of the supersonic jet into the plasma: a cold channel model [4], an electrostatic double-layer shielding model [4], and a rapid plasma cooling leading to the increase in the ionization and dissociation length together with the polarization ExB drift [5]. High density and directionality of the supersonic gas jet allow to ionize a larger fraction of the injected gas and reduce the contact of neutrals with material surfaces. However, the benefits of this new fueling method may be downgraded by its incompatibility with the high performance plasma regimes, namely the H-mode plasmas, and common auxiliary heating methods, such as the radio-frequency waves. The NSTX SGI is mounted on the vacuum vessel port slightly above the midplane (Fig. 1). It is comprised of a graphite nozzle and a modified Veeco PV-10 piezoelectric valve. A graphite shroud protects the assembly from the plasma. Integrated in the shroud are a flush-mounted Langmuir probe and two small magnetic coils for Br and Bz measurements. The assembly is mounted on a Thermionics movable vacuum feedthrough controlled by a PC. The SGI operates at room temperature. The performance of the supersonic nozzle has been characterized in a laboratory setup. Highly collimated jet profiles were measured, and M=4 Mach number was obtained from the supersonic Releigh-Pitot law and impact pressure measurements [6, 7]. Initial NSTX SGI results obtained in the end of FY04 campaign are encouraging: SGI demonstrated high gas jet collimation, good SOL penetration, and compatibility with plasma edge [8].

In the present experiment, fueling efficiency will be evaluated for a variety of plasma conditions. The fueling efficiency is defined as

$$\eta = \frac{dN/dt}{\Gamma_{gas}}$$

where N is the inventory of particles (ions or electrons), and Γ_{gas} is the gas injection rate. The analysis of obtained results should help in understanding the mechanism of the supersonic gas jet penetration into a magnetized plasmas.

3. Experimental run plan

3.1. Measurements and optimization of the SGI fueling efficiency in ohmic plasmas

- Shot to use at T_f = 3 kG to be determined (LSN with PF2L), I_p=0.6-0.8 MA, R_{sep}=152-154 cm. Setup and reference: 2-3 shots
- Use 10-15 Min GDC between shots
- Inject D_2 from SGI in the flat-top phase for 50 ms. Use SGI injection rate of 50-60 Torr l / s (plenum pressure P_0=2000 Torr). Start with SGI head parked at R=160 cm and scan the SGI position by 1 cm inward. Bring the SGI head to within 1 cm of separatrix location (from EFIT). Shot count: 5-8 shots.
- Monitor edge T_e, n_e, impurity rotation, D_α intensity in midplane and divertor, impurity levels. Determine fueling efficiency from density rise measurements.

3.2. Use of SGI for plasma start-up (up to 5 shots)

- For the same ohmic shot template use the SGI instead of Injector # 1 or # 2 during current ramp-up. Note the density ramp rate.
- Monitor edge T_e, n_e, impurity rotation, D_α intensity in midplane and divertor, impurity levels. Determine fueling efficiency from density rise measurements.

3.3. H-mode access with SGI and H-mode flat-top fueling (5 shots)

- Run when NBI is commissioned and H-modes are reproducibly obtained
- Setup an ELM-free or small ELM H-mode with CS gas injector fueling, B_t=0.4 T, I_p=0.8 MA, 2 NBI sources, LSN PF2L configuration, shot template (tbd). (2 shots)
- Add SGI pulse of 100-200 ms during the H-mode phase (2 shots). Use the optimize R_{SGI} obtained in ohmic experiments.

3.4. ELM control

- Setup an H-mode shot with type I ELMs, shot template (tbd). (1-2 shots)
- Add a 200-300 ms SGI pulse during the ELMy period. (2 shots)

3.5.

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

Completed Physics Operations Request and Diagnostic Checklist are attached.

Prerequisite conditions:

- Supersonic gas injector XMP-35 has been run and the SGI is commissioned
- Fast camera (Canadian Photonics or Kodak) is available and mounted on Bay L port window
- NBI and H-mode access conditions are needed for some parts of the experiment.

5. Planned analysis

We plan to use DEGAS 2, UEDGE and TRANSP for fueling efficiency and jet penetration analysis.

6. Planned publication of results

Results will be presented at conferences and / or refereed journals as appropriate.

References

[1] L. Yao et al., Nuc. Fusion 41, 817 (July 2001).
[2] B. Pegourie et al., J. Nuc. Mater. 313-316, 539 (2003).
[3] J. Miyazawa et al., Nucl. Fusion 44, 154 (2004).
[4] J. Yiming, Z. Yan, Y. Lianghua, and D. Jiaqi, Plasma Phys. Control. Fusion 45, 2001 (2003).
[5] J. Bucalossi et. al., in Proc. 29th Int Conf. on Fusion Energy, Lyon 2002 (IAEA, Vienna, 2002).
[6] V. A. Soukhanovskii, H. W. Kugel, R. Kaita, R. Majeski, A. L. Roquemore, Supersonic gas injector for fueling and diagnostic applications on the National Spherical Torus Experiment, Review of Scientific Instruments, October 2004, Volume 75, Issue 10, pp. 4320-4323
[7] V. A. Soukhanovskii, H. W. Kugel, R. Kaita, R. Majeski, A. L. Roquemore, D. P. Stotler, Supersonic gas jet for fueling experiments on NSTX, Paper P2.190, Proceedings of the 31st EPS Conference on Plasma Physics, 28 June - 2 July 2004, London, United Kingdom
[8] V. A. Soukhanovskii, H. W. Kugel, R. Kaita, A. L. Roquemore, First results from NSTX supersonic gas jet fueling experiments, NSTX FY 2004 Results Review, 20-21 September 2004, Princeton, New Jersey . http://nstx.pppl.gov/DragNDrop/Results_Review_04/Soukhanovskii-RR04/

PHYSICS OPERATIONS REQUEST

Fueling NSTX plasmas with Supersonic Gas Jet **OP-XP-???**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): ______ Flattop start/stop (s): _____/_____

I_P (MA): ______ Flattop start/stop (s): _____/_____

Configuration: **Inner Wall / Lower Single Null / Upper SN / Double Null**

Outer gap (m): _____, Inner gap (m): _____

Elongation κ: _____, Triangularity δ: _____

Z position (m): **0.00**

Gas Species: **D / He**, Injector: **Midplane / Inner wall / Lower Dome**

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): _____, Duration (s): _____

ICRF – Power (MW): ____, Phasing: **Heating / CD**, Duration (s): _____

CHI: **On / Off**

Either: List previous shot numbers for setup: ______________________________

Or: Sketch the desired time profiles, including inner and outer gaps, κ, δ, heating, fuelling, etc. as appropriate. Accurately label the sketch with times and values.

DIAGNOSTIC CHECKLIST

Diagnostic	**Need**	**Desire**	**Instructions**
Bolometer – tangential array		✓	
Bolometer array - divertor		✓	
CHERS		✓	
Divertor fast camera	✓		
Dust detector			
EBW radiometers			
Edge deposition monitor			
Edge pressure gauges	✓		
Edge rotation spectroscopy		✓	
Fast lost ion probes - IFLIP			
Fast lost ion probes - SFLIP			
Filtered 1D cameras		✓	
Filterscopes		✓	
FIReTIP		✓	
Gas puff imaging			
Infrared cameras		✓	
Interferometer - 1 mm		✓	
Langmuir probe array		✓	
Magnetics - Diamagnetism			
Magnetics - Flux loops	✓		
Magnetics - Locked modes			
Magnetics - Pickup coils	✓		
Magnetics - Rogowski coils	✓		
Magnetics - RWM sensors			
Mirnov coils – high frequency			
Mirnov coils – poloidal array			
Mirnov coils – toroidal array			
MSE			
Neutral particle analyzer		✓	
Neutron measurements			
Plasma TV	✓		
Reciprocating probe		✓	
Reflectometer – core		✓	
Reflectometer - SOL		✓	
RF antenna camera			
RF antenna probe			
SPRED		✓	
Thomson scattering	✓		
Ultrasoft X-ray arrays		✓	
Visible bremsstrahlung det.		✓	
Visible spectrometers (VIPS)		✓	
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray PIXCS (GEM) camera			
X-ray pinhole camera			
X-ray TG spectrometer			