Characterization of Neutral Fueling During LHI in the Pegasus-III Experiment

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Pegasus-III Experiment

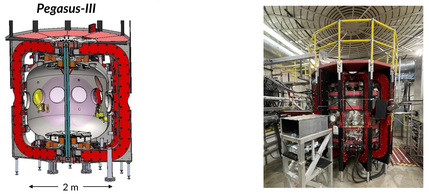
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Pegasus-III to Study Non-Solenoidal Startup

Goal: develop validated physics and technology basis for MA-class startup
- Toroidal field capability increased to 0.6T
- Pegasus-III explores a variety of startup systems:
  - Local Helicity Injection (LHI)
  - Coaxial Helicity Injection (CHI)
  - Radio-frequency(RF) assist and sustainment
- Fueling is important to LHI injector technology



- For more information, see Reusch *et al.*, *YP11.00029*

Pegasus-III Local Helicity Injection Capability

LHI relies on magnetic relaxation and helicity conservation to generate I_p
- Taylor Relaxation limits I_p

$$I_p \leq I_{TL} \sim \sqrt{I_{TF} I_{inj} / w}$$

- Helicity balance also limits Ip

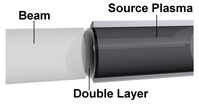
$$I_p = \frac{A_p V_{LHI}}{2\pi R_0 \langle \eta \rangle} \approx \frac{V_{inj} A_{inj}}{2\pi R_0 \langle \eta \rangle} \left(\frac{B_{inj}}{B_0} \right)$$

- Plasma current scales like injector area and voltage

LHI streams in startup phase



Injector impedance related to double layer physics
- Biasing the injector creates double layer
- Rapid potential drop over λ_{Debye} accelerates electrons

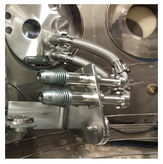


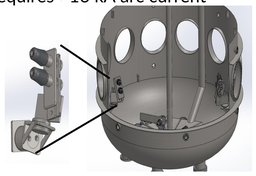
$$I_{inj} = min\{n_{edge}, \beta n_{arc}\} e A_{inj} \sqrt{\frac{2eV_{inj}}{m_e}}$$

Hinson, *et al.*, Phys Plasmas **23**, 052515 (2016)

- Injector impedance scales like neutral density

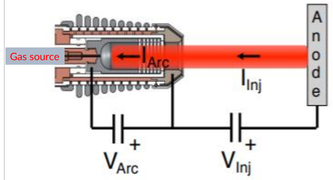
Two arrays of 2 x 4 cm^2 injectors at 180° toroidal spacing, 4kA per injector
- 16kA current injection capacity requires >16 kA arc current





Neutral Fueling Can Arise from a Variety of Mechanisms

Plasma fueled from arc cathode



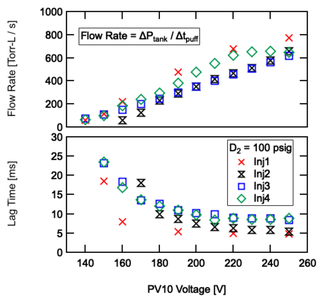
Fueling process:
- Arc plasma fueled by neutral gas, then biased against the wall to extract electrons

Minimum fueling is set by operating current

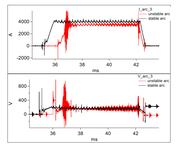
$$I_{gas}[A] = 11Q\left[\frac{Torr - L}{s}\right]$$

$$Q = \frac{dP_{tank}(t)}{dt} V$$

Gas valves provide required flow

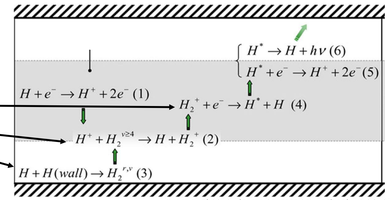


Arc instability is a result of insufficient fueling



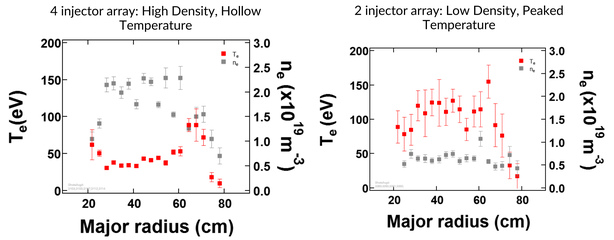
Several mechanisms inside the injector arc contribute to neutral sources:
- Molecular disassociation
- Charge exchange
- Wall recombination

Hydrogen plasmas suffer from large volume recombination rates at low temperature and density



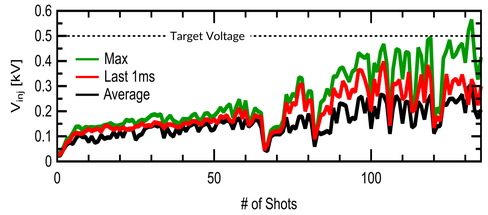
W A J Vijvers et al 2010 Plasma Sources Sci. Technol. 19 065016

Initial Thomson scattering results provide context for density control

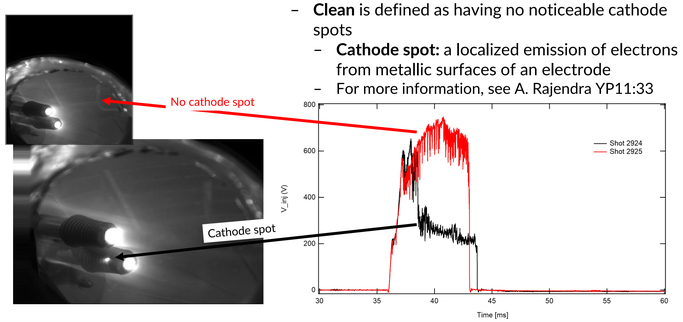


Injector Conditioning is Required for Stable Operation

Injector conditioning: Verification of injector function at desired high voltage
- Discharges were performed until sufficient levels of V_{inj} achieved
  - Required about 150 shots
    - <5% of injector lifetime



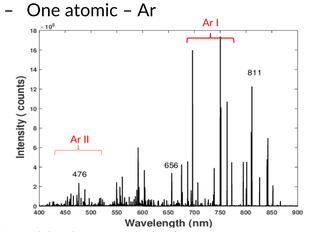
Consistent, clean, and accurate performance of the injectors is required:
- **Clean** is defined as having no noticeable cathode spots
  - **Cathode spot:** a localized emission of electrons from metallic surfaces of an electrode
  - For more information, see A. Rajendra YP11:33



Experiments Planned to Characterize Arc Fueling Properties

Goal: Study and understand what processes are responsible for neutral leakage from the arc plasma
- If arc neutral behavior can be characterized, it can be mitigated

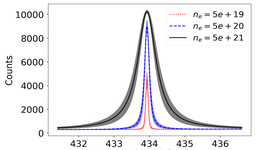
Proposed experiment:
- Operate helicity injectors with two different gas types
  - One molecular – D_2
  - One atomic – Ar



R. Rane et al Phys. Plasmas 25, 093509 (2018)

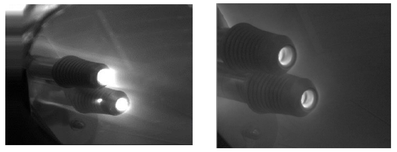
Use Visual Survey Spectroscopy to characterize neutral content of main chamber
- D_α emission for D_2 fueling
- Ar I and Ar II lines for Ar fueling

Use High-Resolution Spectroscopy to quantify neutral temperature and n_e
- **Thermal (Doppler) broadening**
  - Temperature of the arc gives the maximum energy for charge exchange neutrals
- **Stark Broadening**
  - Electron density characterizes injector impedance



Predicted Stark broadening lines shape show good sensitivity for expected density

$D\alpha$ emission measurements can put an upper bound on neutral density



Imaging of injectors before (left) and after (right) installation for a $D\alpha$ filter.

Neutral fueling will be characterized in Pegasus-III

- The helicity injectors have been conditioned to reduce cathode spot formation during startup
  - Gas flow for injector arrays is successfully characterized in terms of flow rate and lag time
- Experiments will be conducted to assess the level of neutral leakage from the arc plasma
  - Changing the injector fuel gas to Ar allows for distinction between injector and vessel fueling in plasma emissions

References: [1] Hinson, *et al.*, Phys Plasmas **23**, 052515 (2016) [2] W A J Vijvers et al (2010) Plasma Sources Sci. Technol. 19 065016, [3] R. Rane et al Phys. Plasmas 25, 093509 (2018)

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