Investigation of neutral beam arc chamber failure during helium operations at DIII-D

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**BACKGROUND**

- The DIII-D Tokamak project conducts critical research focused on supporting the design and operation of next-generation devices such as ITER.

- **Neutral Beam Injection** is an important capability, providing both heating and fueling for the plasma fusion.
  - DIII-D comprises 8 Common Long Pulse Source (CLPS) ion sources.
  - 2.5 MW each, injection energy up to 80 keV.

- The working principle is the release of primary electrons through thermoelectric emission from heated filaments, which ionize the background gas by falling through an applied arc potential. Efficiency is improved by the magnetic confinement of energetic electrons through multicusp fields.

**DESIGN AND CAPABILITIES**

- Cylindrical vacuum chamber: ~ 2.6 L plasma volume.
- Checkerboard high-temp Samarium-Cobalt magnet array.
- 4 flexible ports for experiments and diagnostics.

**HYPOTHESES**

- Evaporation of the filaments lead to the release of tungsten material into the plasma. Additionally, the presence of operating gas, impurity, and in specific cases argon ions at arc energy is detrimental. Above certain threshold energies sputtering yields exceed that of evaporation. Deposited filament material forms a coating on internal surfaces.
- If a conducting coating is formed on the insulating surfaces short-circuits could follow.
- Migration of helium within the polymer insulation material can cause breakdown at arc voltage.
- The accumulation of impurity argon ions, specifically during helium operation, can lead to deteriorating performance.

**PRELIMINARY RESULTS**

- Preliminary results were recently obtained. The multicusp confinement field is working as intended and arc currents up to 19 A are produced at a filament current and arc voltage of 100 A and 75 V, respectively.

**CONCLUSION & FUTURE RESEARCH**

- A table-top ion source was designed and built with similar geometry and plasma parameters as the DIII-D Neutral Beam System.
- The initial purpose was to replicate plate-to-plate arcing during helium operation, for which the main hypothesis is the deposition of sputtered and evaporated tungsten.
- This damage was successfully reproduced; the device is working as planned.
- Future research involves more detailed characterization of the source performance by the analysis of acquired EEDF profiles and optical spectra.
- Iterative development of new insulation solutions is planned. Live testing of new gasket design on the DIII-D Neutral Beam system will follow.
- To expand the scope of potential research future work could involve extending the setup with accelerator grids for the production of actual ions.

**VALIDATION**

- COMSOL Multiphysics was used to validate design.
- Tracing of primary electron orbits in the multicusp field shows confinement.
- From heat transport analysis follows steady-state operational capability at a maximum of 4 kW of total electrical power.

**MOTIVATION**

- A table-top ion source with similar plasma parameters will allow for R&D not possible on the actual sources.
- By reproducing the issues and iteratively trying new ideas on this test setup new insights can be gained on how to improve the ion source performance, particularly under helium operation.
- Therefore design requirements are as follows:
  - Simulate intense geometry and magnetic confinement.
  - Flexible diagnostic options.
  - Capability of steady-state operation to rapidly mimic campaign-length ion source operation.

**BREAKDOWN REPRODUCTION**

- The issue of insulation breakdown was successfully reproduced at a filament current and arc voltage of 90 A and 120 V, respectively.
- Arcing occurred inside across the back plate and filament plate, partially destroying the Mylar gasket material.
- The oxidation pattern indicates the heat profile during the arcing event.
- Observed arc spots do not correlate with filament position.

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