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

- DIII-D comprises 2 Common Long Pulse Source (CLPS) ion sources at 2.5 MW each
- Injection energy up to 80 keV

The working principle is the release of primary electrons through thermofield 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.

Helium operation is important for research regarding the ITER pre-nuclear phase

During helium operation ion source performance deteriorates and arcing damage occurs, limiting DIII-D helium capabilities

- Arcing occurs across plates with arc potential differences, through Mylar gasket material
- Typically after 100s of helium discharges
- Source repairs required, which are time and labor intensive

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 spuffing yields exceed that of evaporation. Deposited filament material forms a coating on internal surfaces.

If a conducting coating is formed on the insulating surfaces 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

New insulation designs are being developed and tested

- A design with the insulation edges receded into the plate gaps by 1/8 inch, in order to prevent the direct deposition of released filament material
- An annular ring of Mylar gasket material to provide a more temperature-resistant barrier between the plasma and the Mylar gasket
- A ceramic ring positioned inside the plate gaps to shield the polymer gasket material from penetrating helium, and provide a high-temperature barrier
- Additional ceramic ridges in this ceramic ring could increase the plate-to-plate path length in order to prevent the formation of a conducting path

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

The relation between resulting arc current and applied filament current is found to be quadratic

- This is due to the quadratic nature of Richardson’s Law describing thermionic emission from a heated filament

The developed plasma electron density and temperature are found to be 3.0 \times 10^{17} \text{m}^{-3} and 1.55 \text{eV}, respectively

A table-top ion source was designed and built with similar geometry and plasma parameters as the DIII-D Neutral Beam System to test the reliability of the design and plasma performance. The initial performance of this source is encouraging, indicating good potential for further development.

By reproducing the issues and iterating new ideas 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

- 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

The arc spots do not correlate with filament position

The damage was successfully reproduced; the device is working as planned

To expand the scope of potential research future work could involve extending the setup with accelerator grids for the production of actual ions

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

HYPOTHESES

- 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

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

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The DIII-D Neutral Beam System & Carl Fremlin

PRELIMINARY RESULTS

- 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

- The relation between resulting arc current and applied filament current is found to be quadratic
  - This is due to the quadratic nature of Richardson’s Law describing thermionic emission from a heated filament
  - The developed plasma electron density and temperature are found to be 3.0 \times 10^{17} \text{m}^{-3} and 1.55 \text{eV}, respectively

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

- The relation between resulting arc current and applied filament current is found to be quadratic
  - This is due to the quadratic nature of Richardson’s Law describing thermionic emission from a heated filament

- The developed plasma electron density and temperature are found to be 3.0 \times 10^{17} \text{m}^{-3} and 1.55 \text{eV}, respectively