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Optimization of Hall Thruster Magnetic Field Topography

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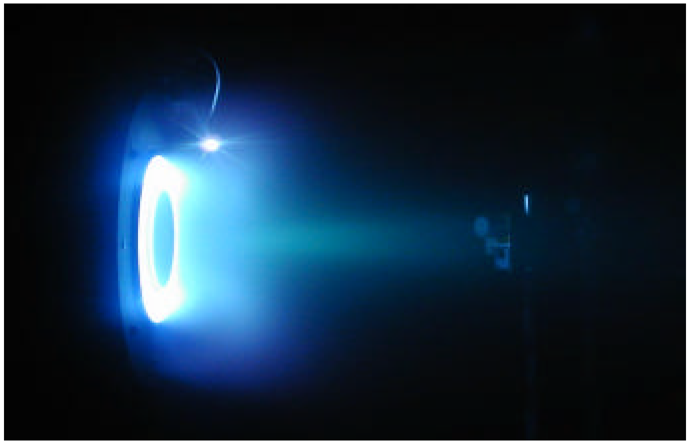

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Introduction

- Optimizing the magnetic field topography is key to maximizing the system performance of Hall thrusters. To first order, the equipotentials follow the B-field lines, so a map of the B-field gives some indication of how ions are accelerated out of the thruster. The magnetic field also contributes to the azimuthal ExB drift experienced by the electrons and must be of sufficient magnitude to confine electrons within the discharge chamber while not confining ions.

- Although key to the performance of the Hall thruster, very little has been published on the subject of B-field topography primarily due to the proprietary nature of many of the designs used by the various manufacturers. It is the objective of this research to examine the various aspects of designing Hall thruster magnetic circuits and make recommendations of how to improve system performance. This data should also prove useful to researchers designing other laboratory Hall thrusters.

Objectives

- Validate the 3D magnetostatic solver Magnet 6 by comparing with experimental Hall probe data.
- Modify the existing magnetic circuit of the P5 using the 3D magnetostatic solver to predict field topographies.
- Test the new magnetic circuit configurations by measuring the divergence angle of the ion beam using a Faraday probe.

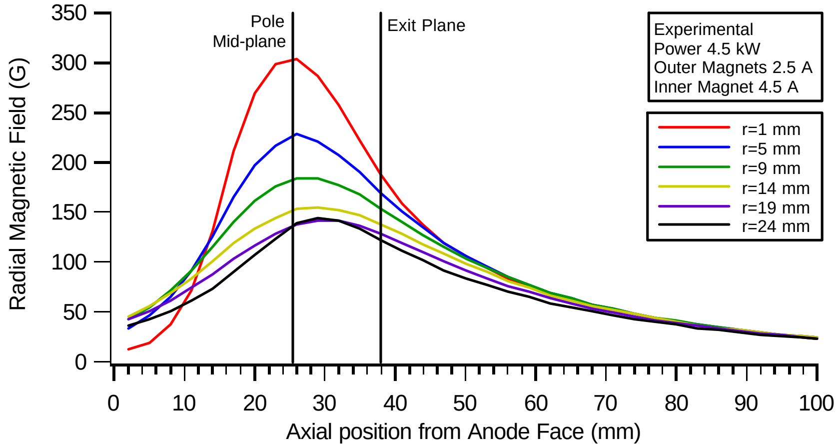
U-M/AFRL P5 5 kW Hall Thruster

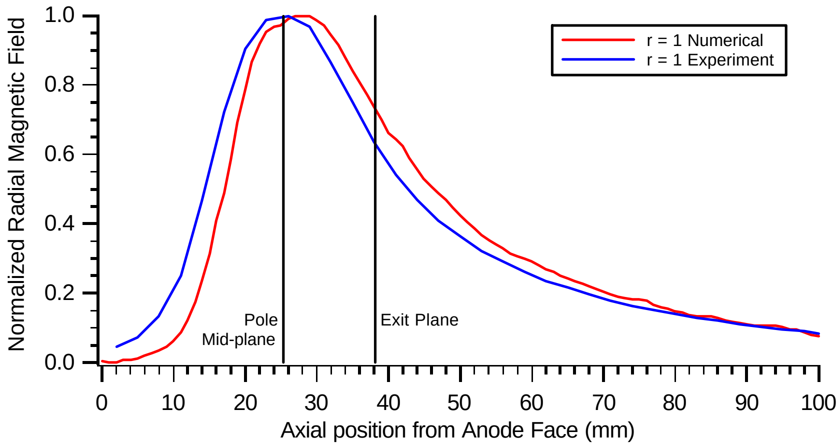
- Laboratory thruster developed by PEPL & AFRL
- At design point of 5 kW: 2330 s specific impulse, 246 mN thrust, and 57% efficiency.

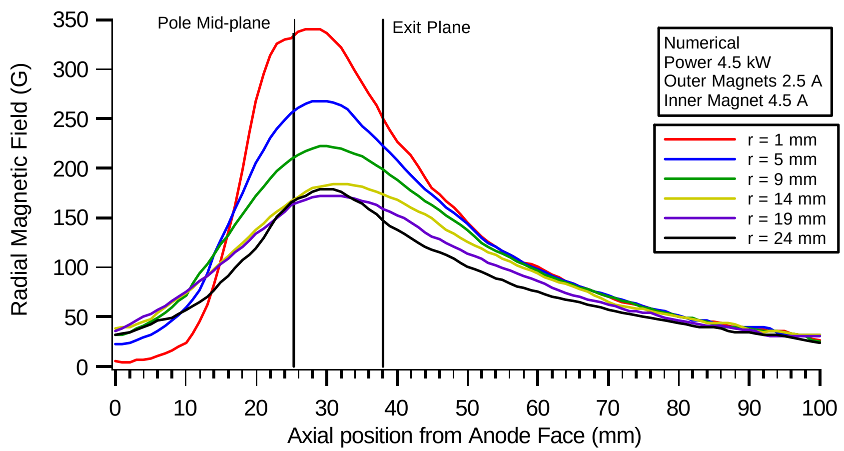
  These performance values are comparable to commercial thrusters.
- Operating Conditions for these experiments:

Voltage (V)	Current (A)	Power (kW)
300	5.4	1.6
300	10.0	3.0
300	15.0	4.5

Current Design - Experimental vs. Numerical Radial Magnetic Field Profiles

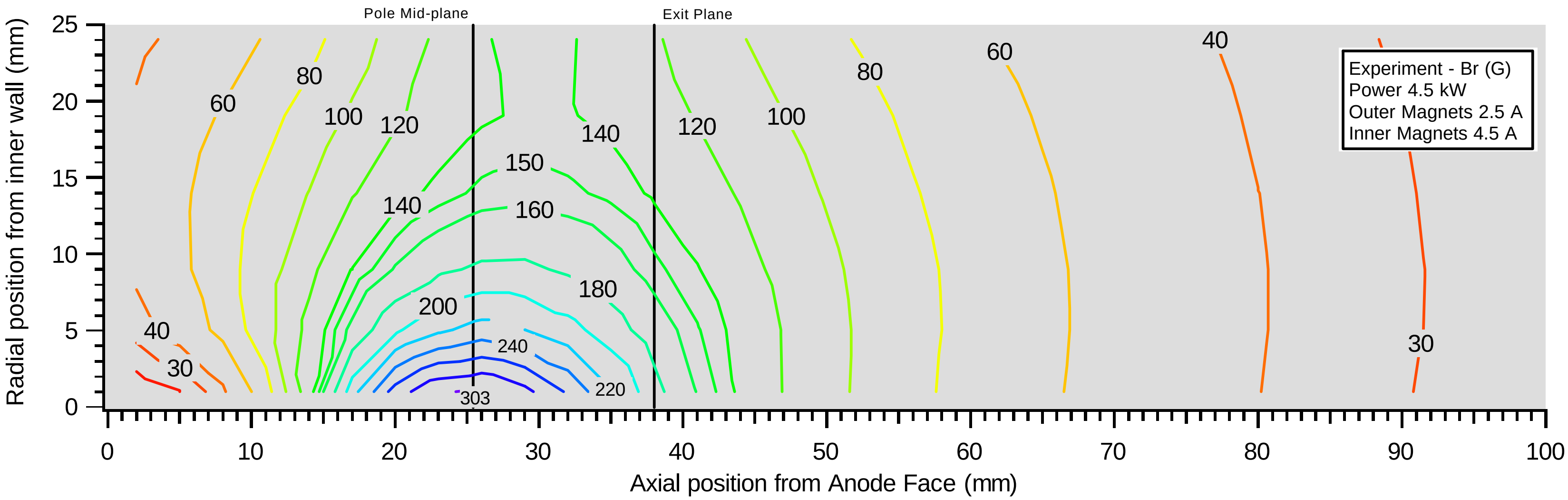


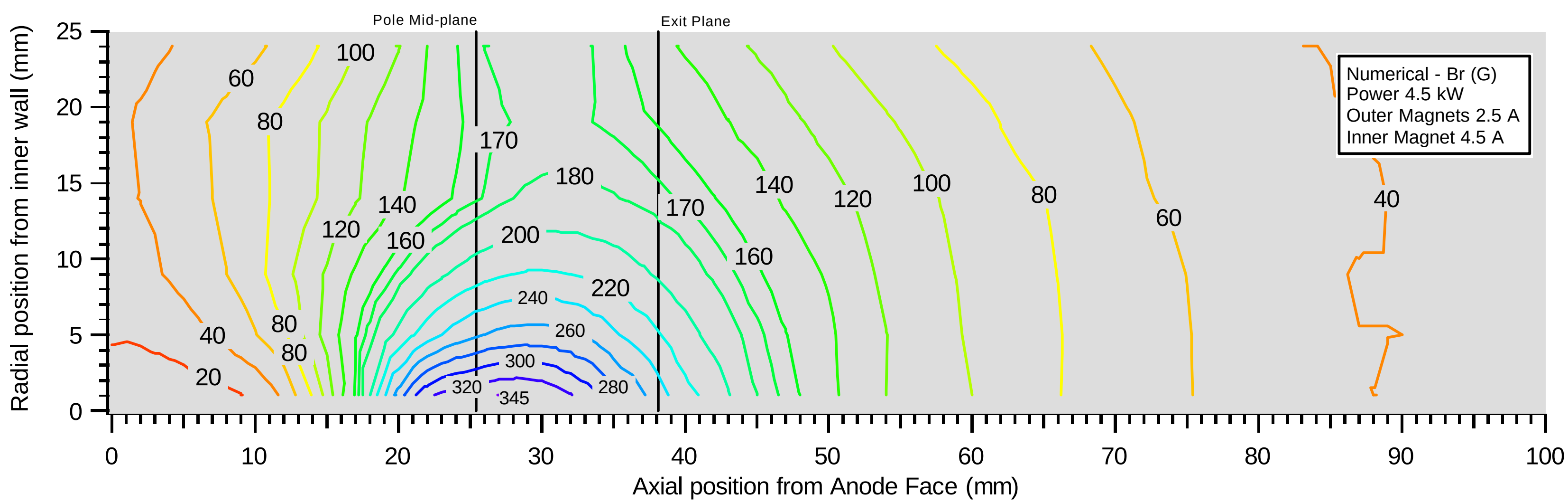




- •Experimental data taken with a Hall probe at atmospheric conditions
- •Numerical data computed using Magnet 6, a 3D unstructured mesh magnetostatic solver
- •Peak fields over predicted by ~20%. Most likely because the BH curve of the iron used in the thruster is not precisely known.
- •Curvature of the field lines is closely approximated as shown in the normalized plot.
- •Conclusion: Magnet is capturing the field shape adequately enough to be used as a design tool.

Current Design - Experimental vs. Numerical Radial Magnetic Field Contours





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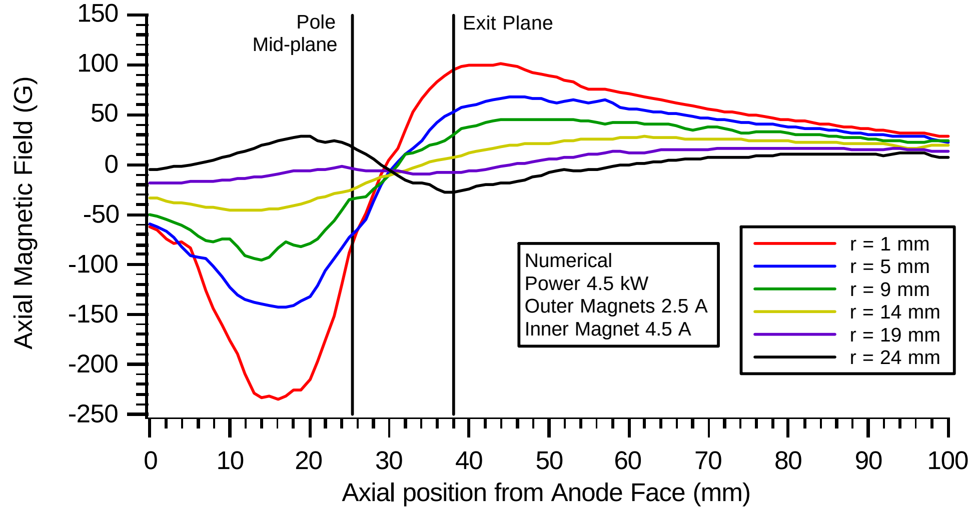
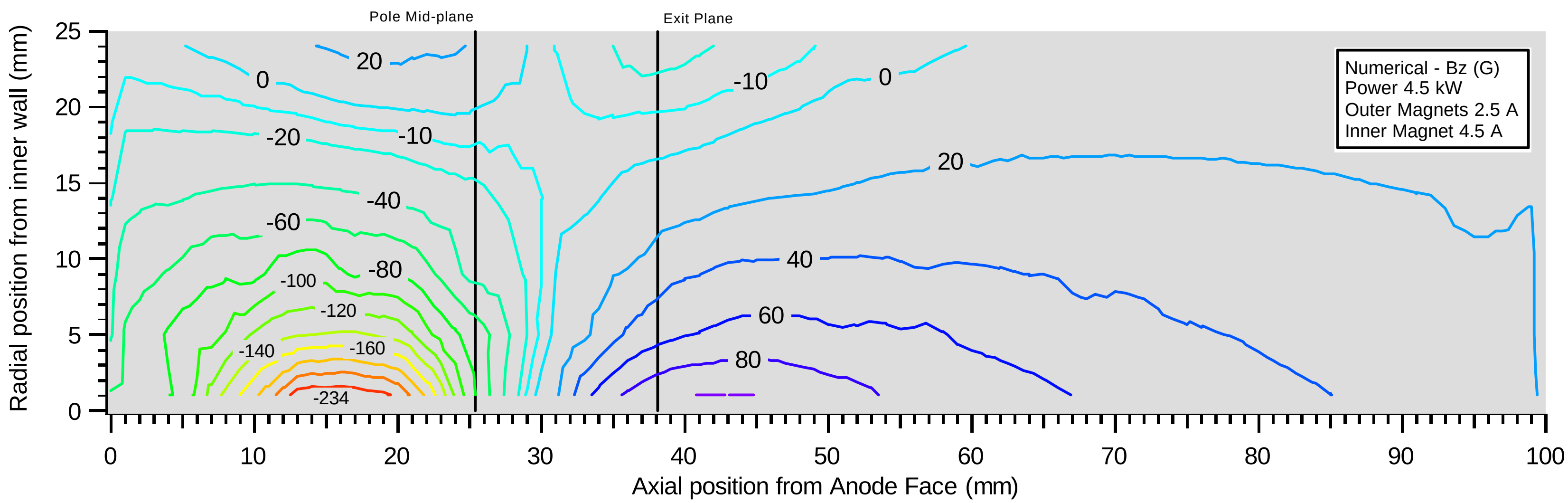
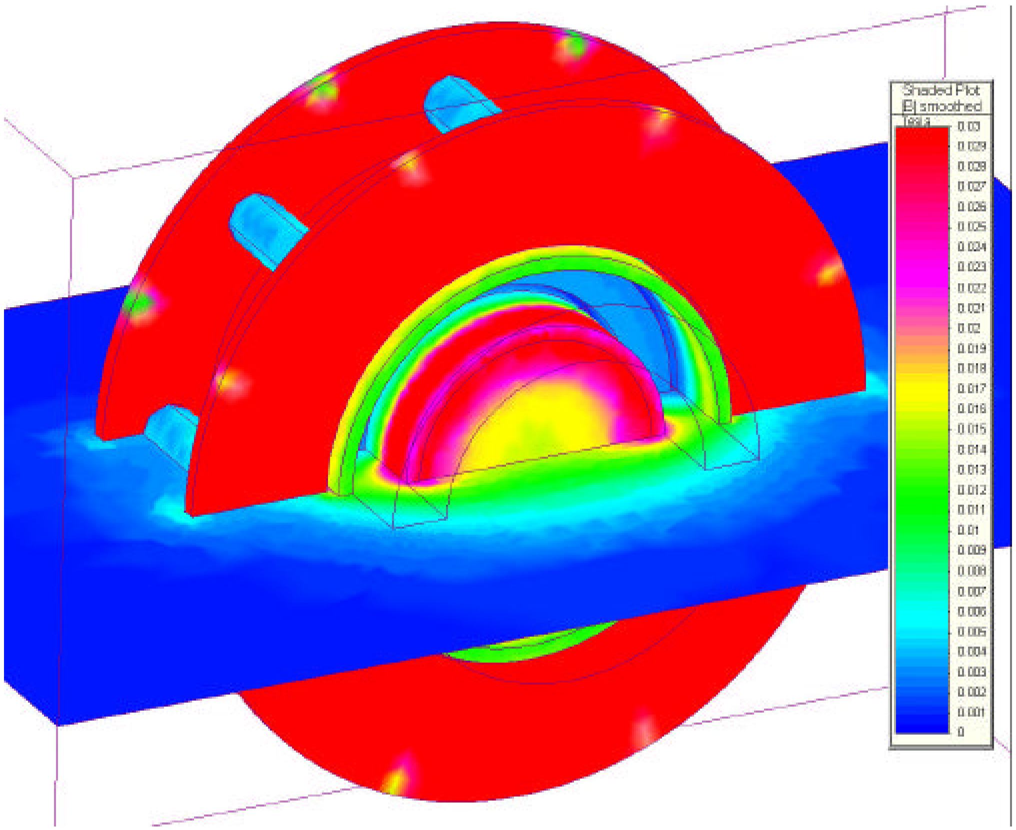
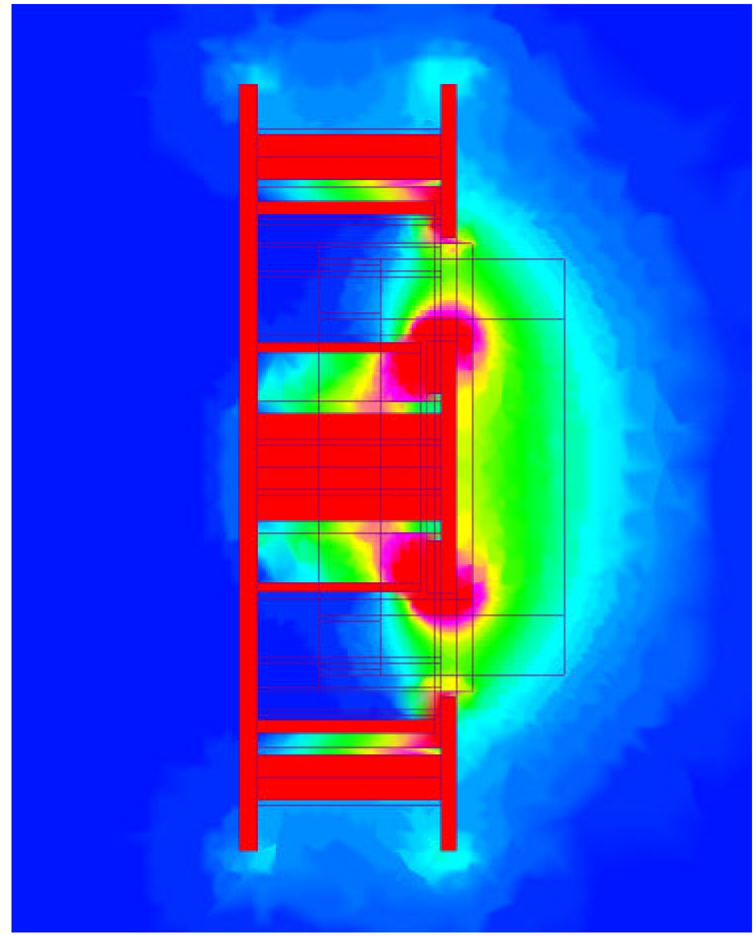
Current Design – Numerical
Axial Magnetic Field Profiles & Contours





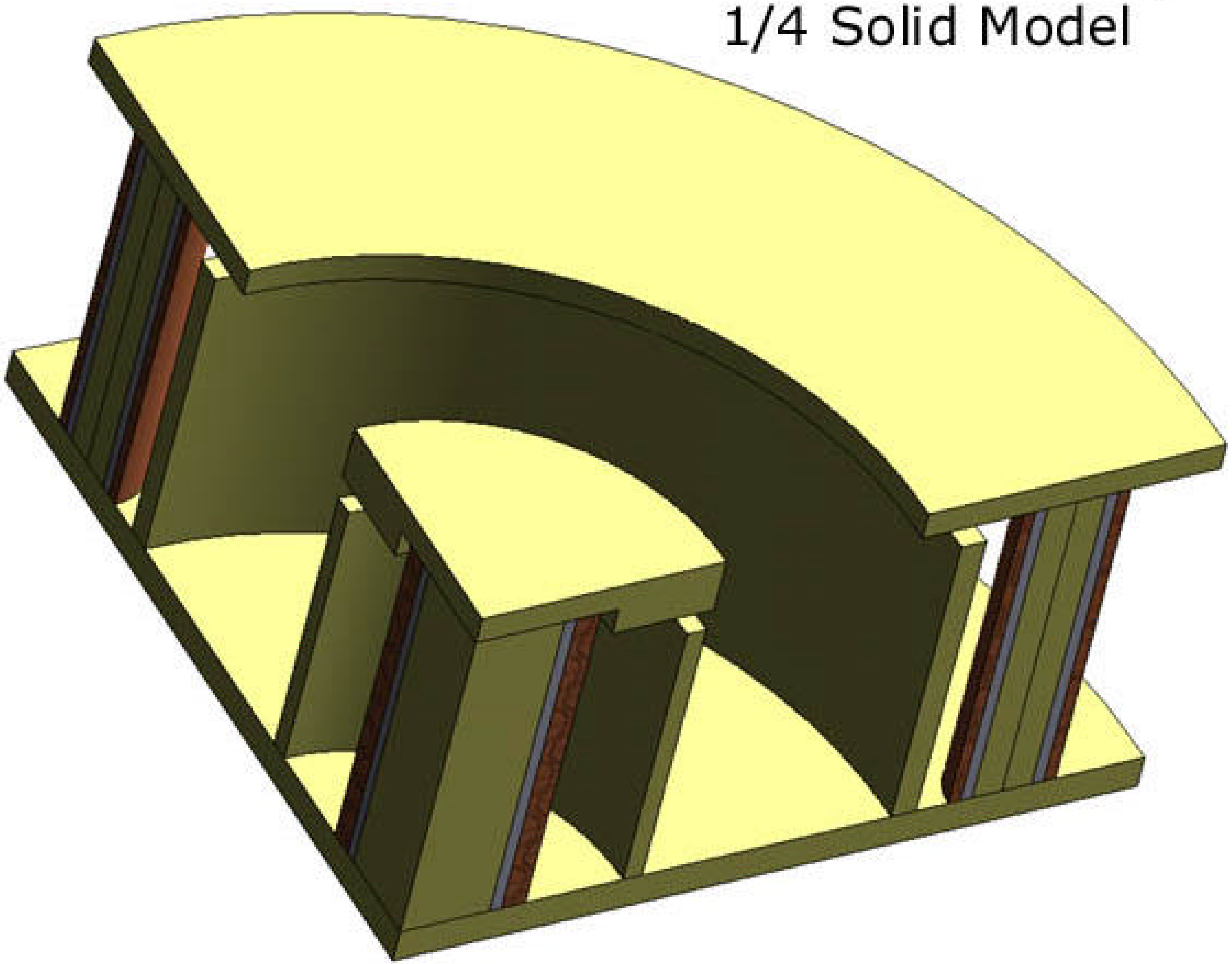
Numerical B Field Simulation



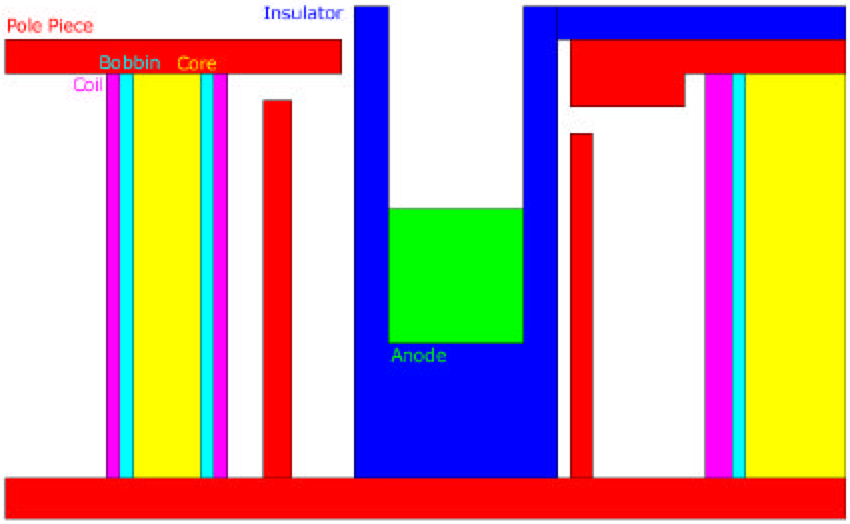


3kW, Magnitude of B

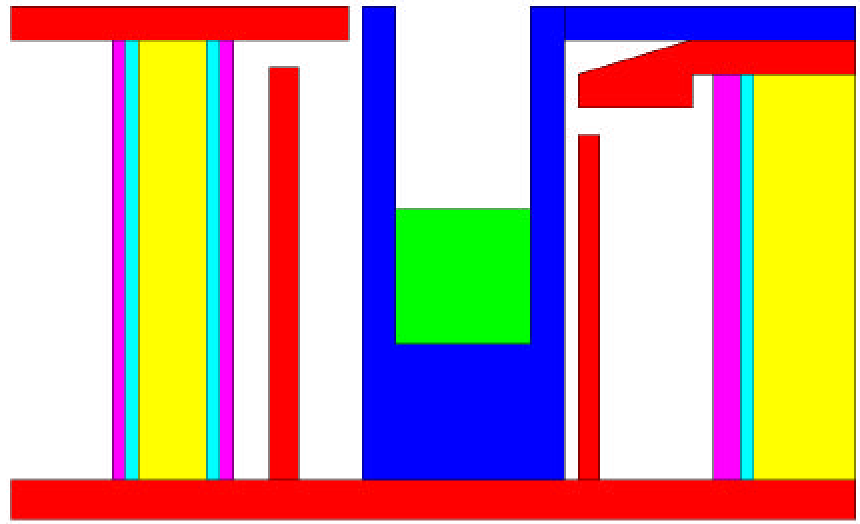
Numerical Solid Model Geometry



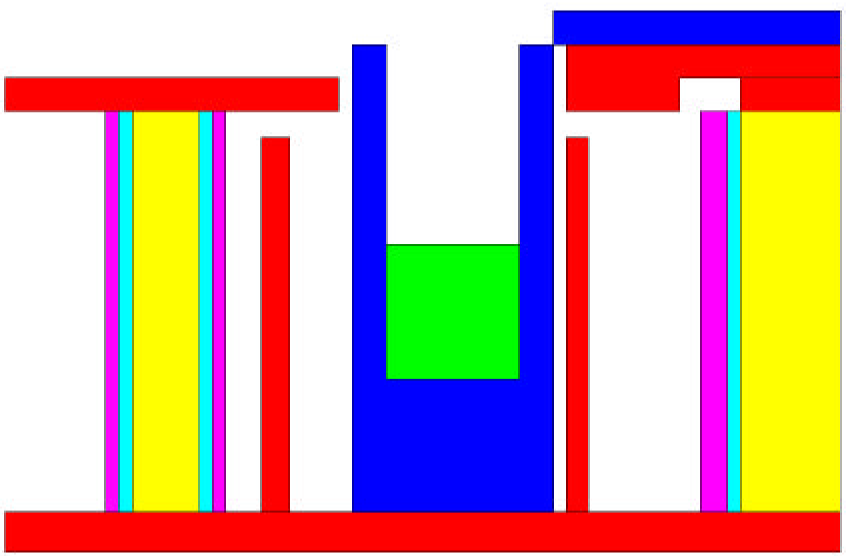
Magnetic Circuit Modification Schematics



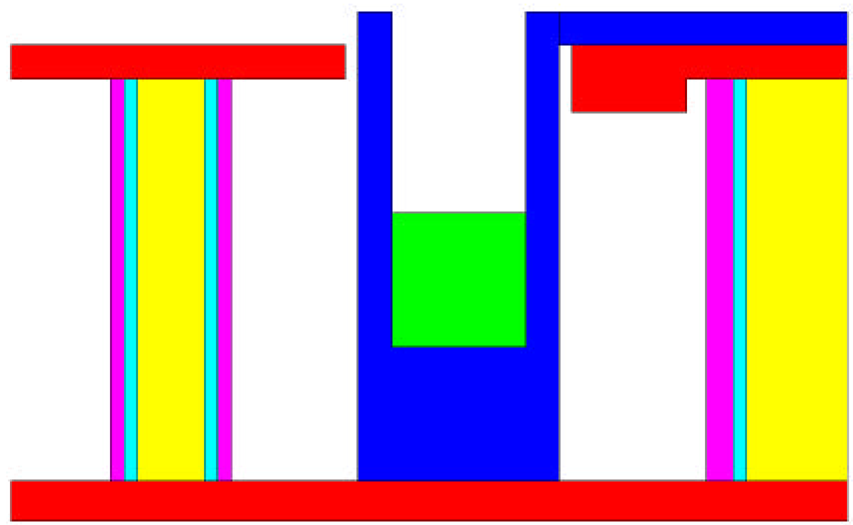
Current Design



Inner Pole Chamfer, Ext. Outer Front Pole

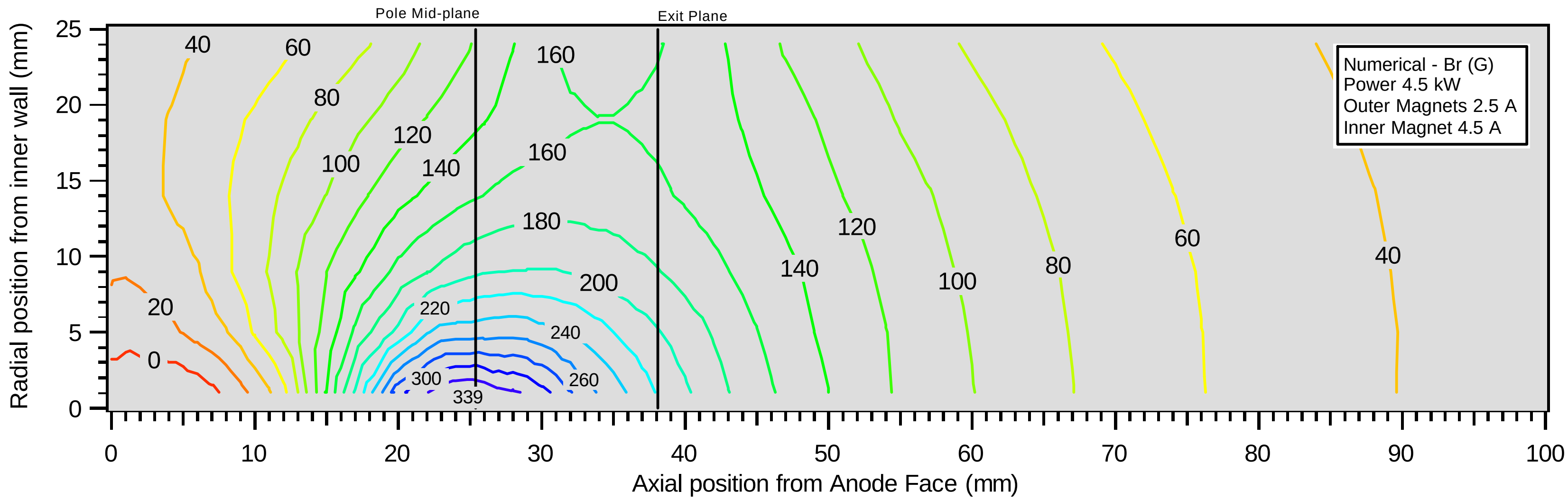


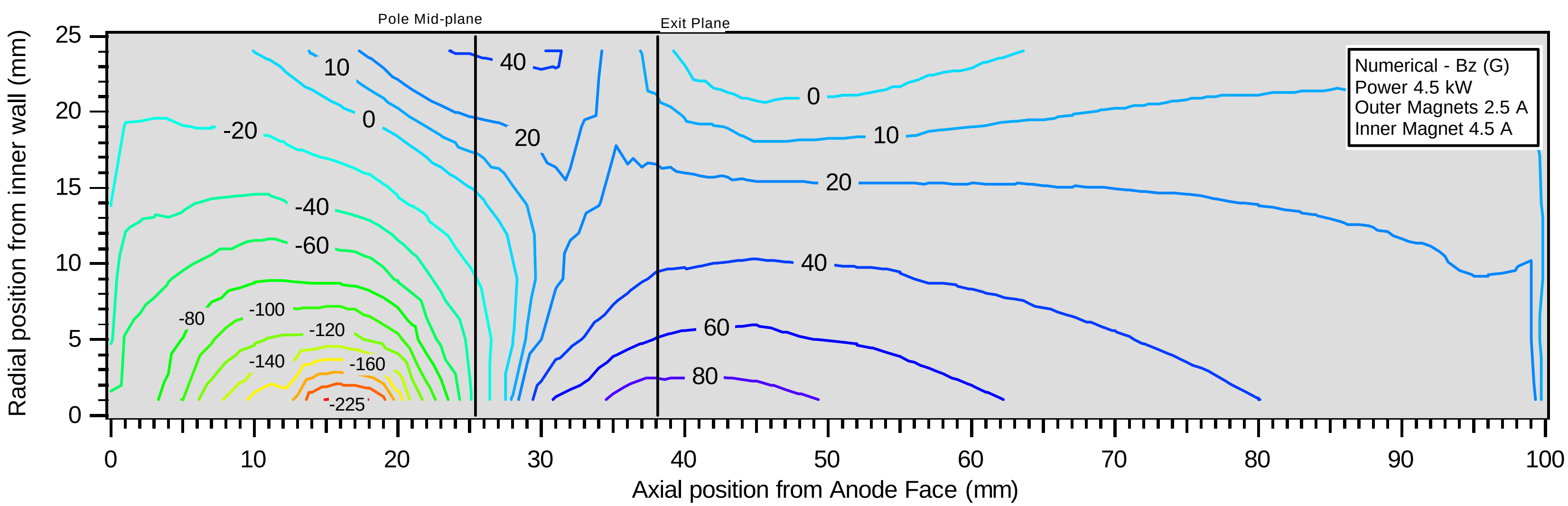
Extended Inner Front Pole



No Screens

Inner Pole Chamfer, Extended Outer Pole Radial and Axial Magnetic Field Contours





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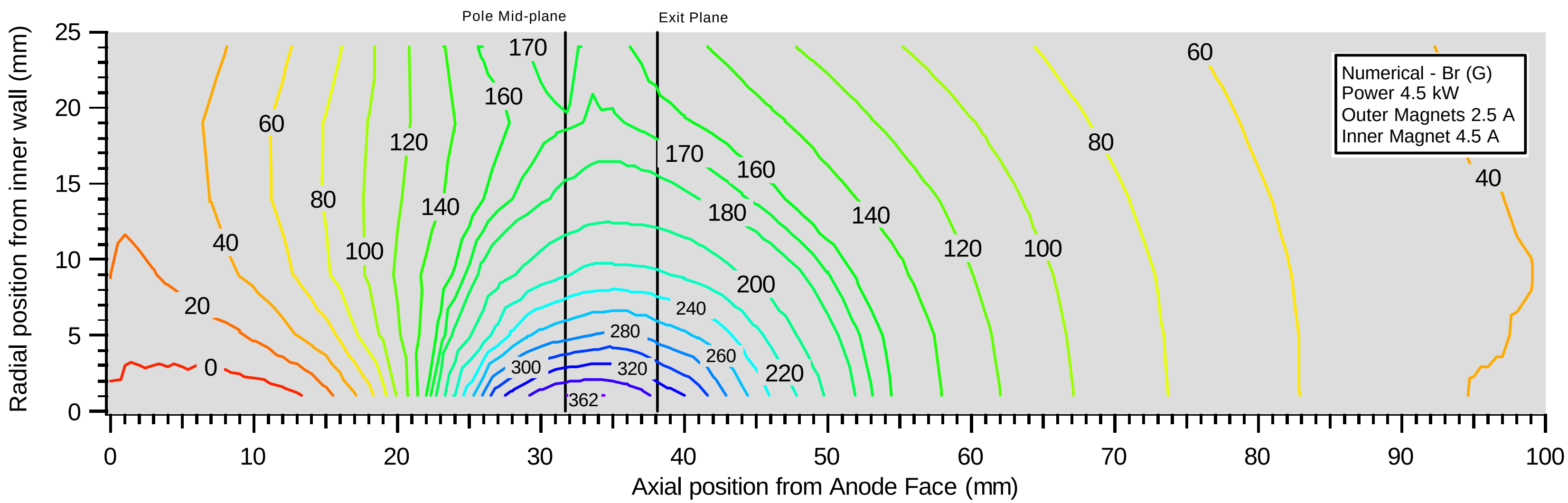
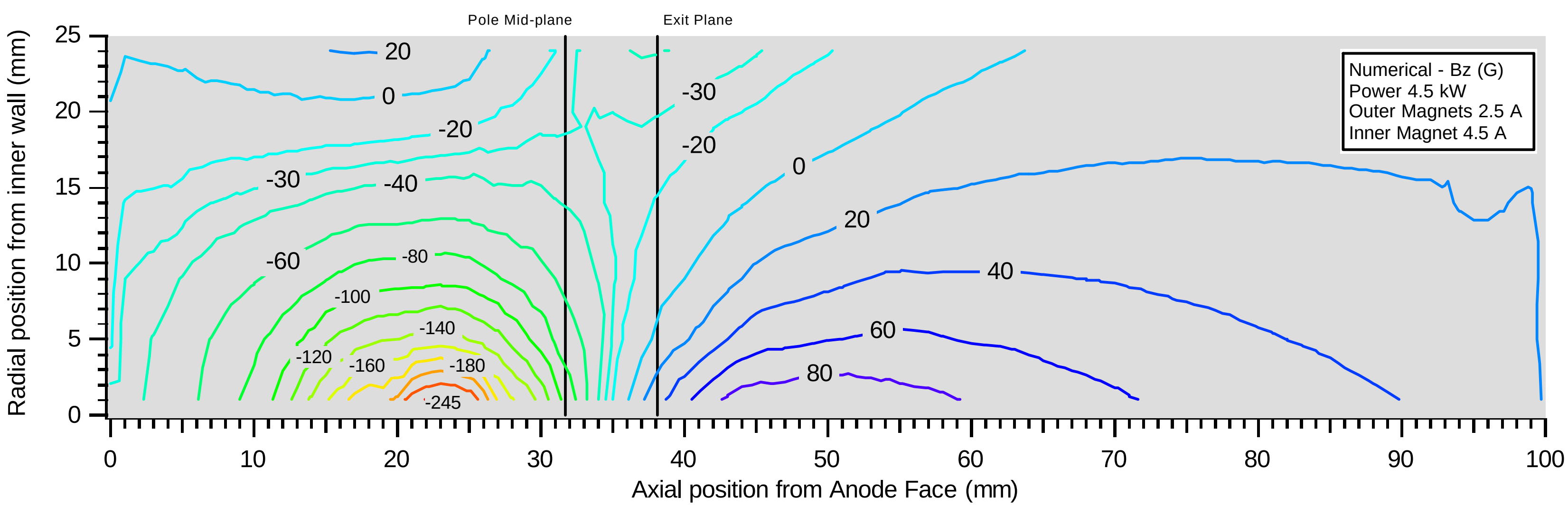
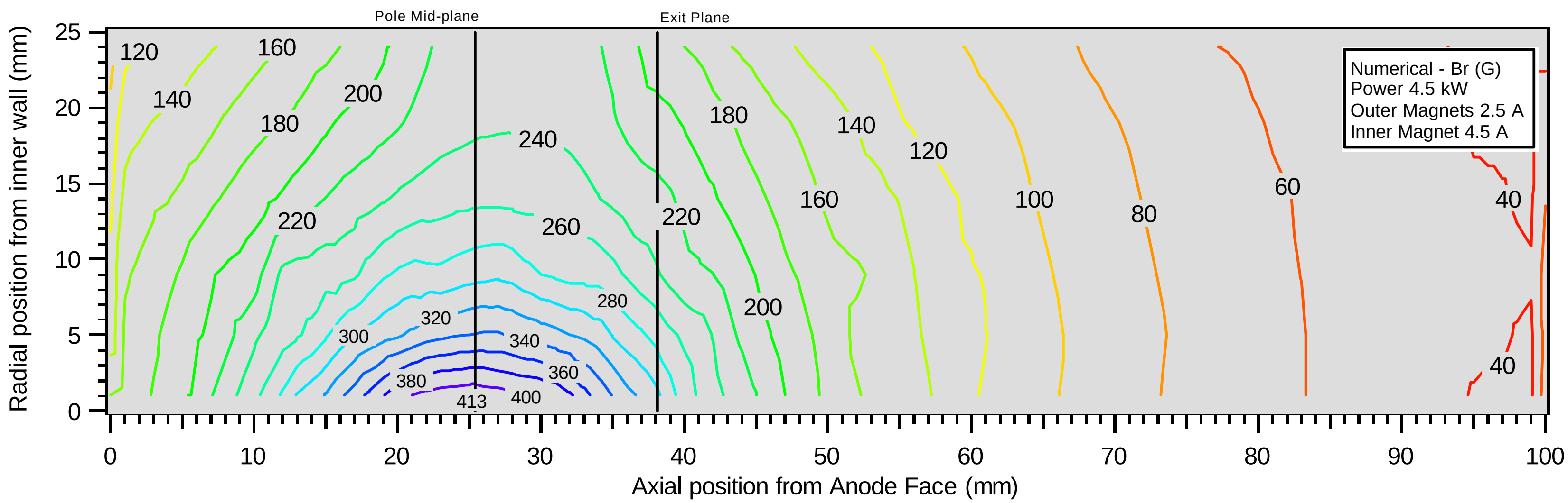
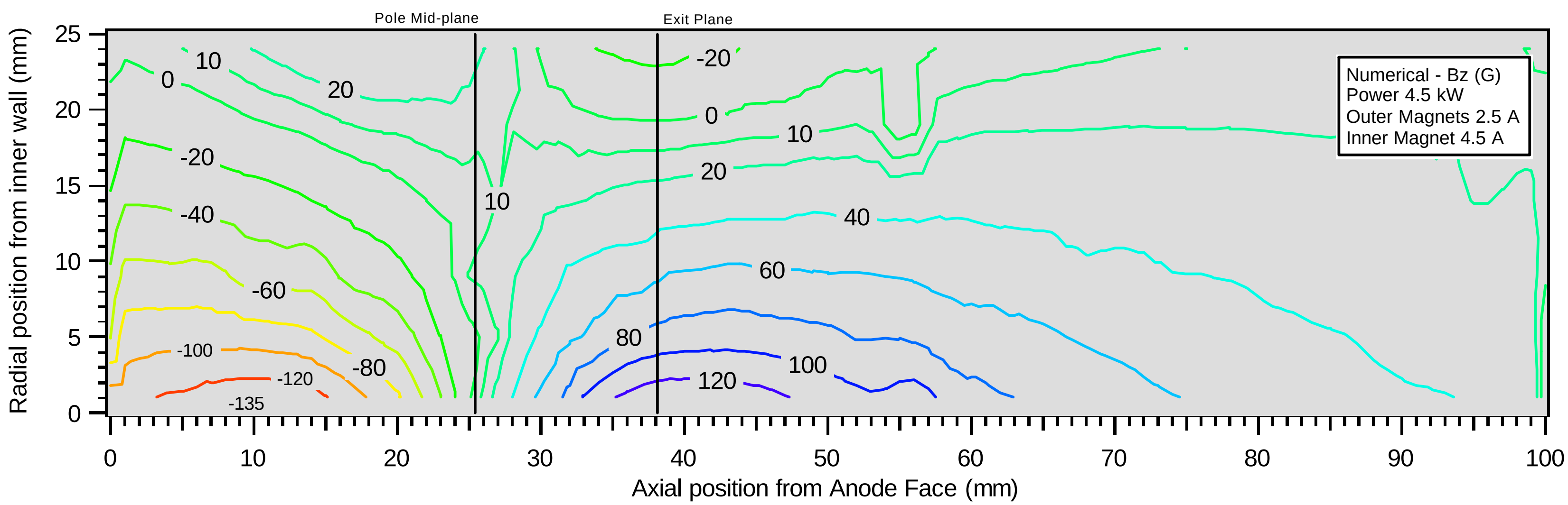
Extended Inner Pole
Radial and Axial Magnetic Field Contours





No Magnetic Screens
Radial and Axial Magnetic Field Contours





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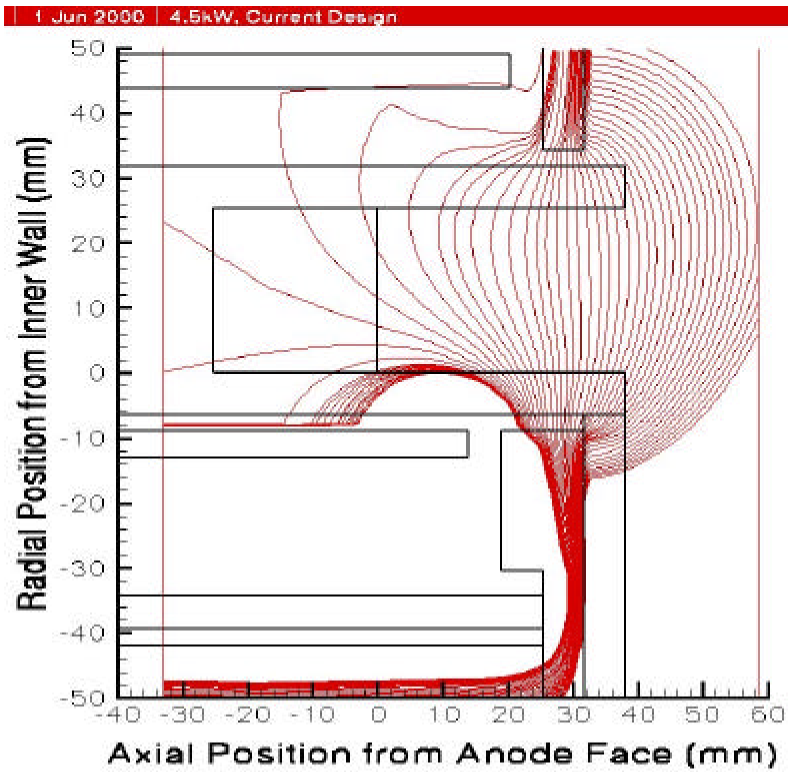
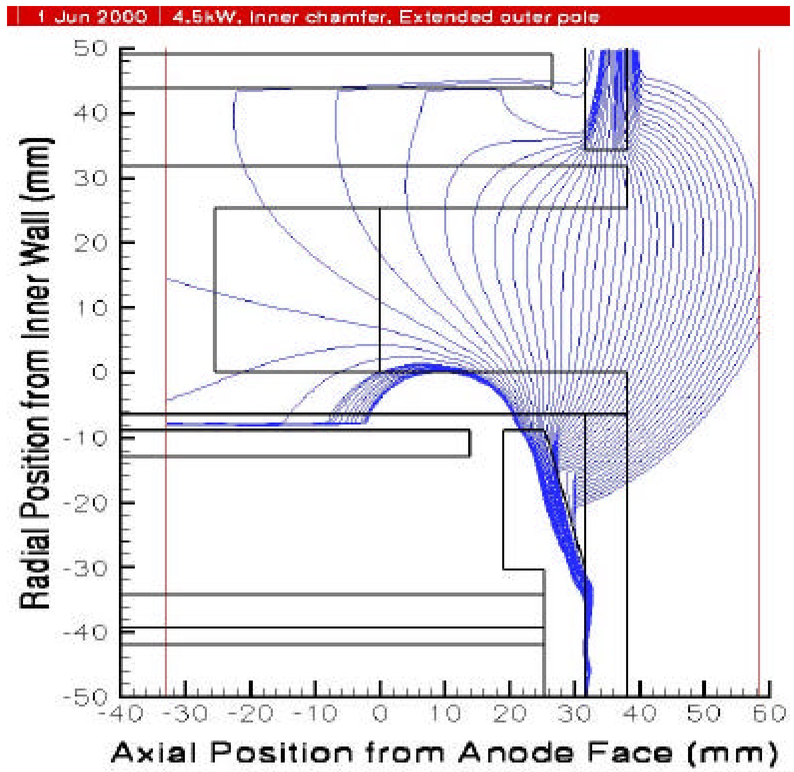
Current Design and Inner Chamfer, Ext. Outer Pole Magnetic Field Lines

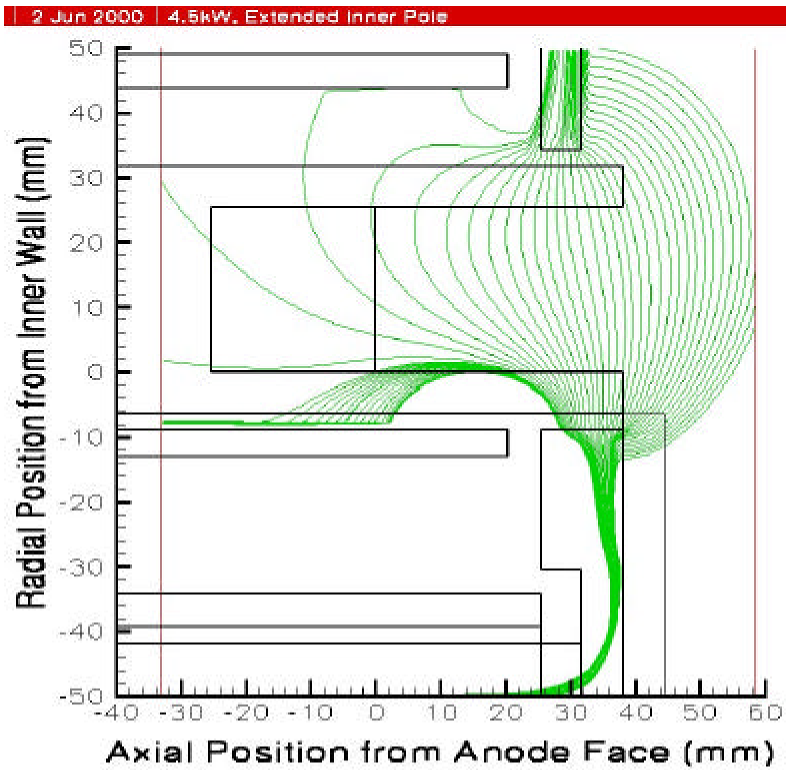


Current Design – aligned poles

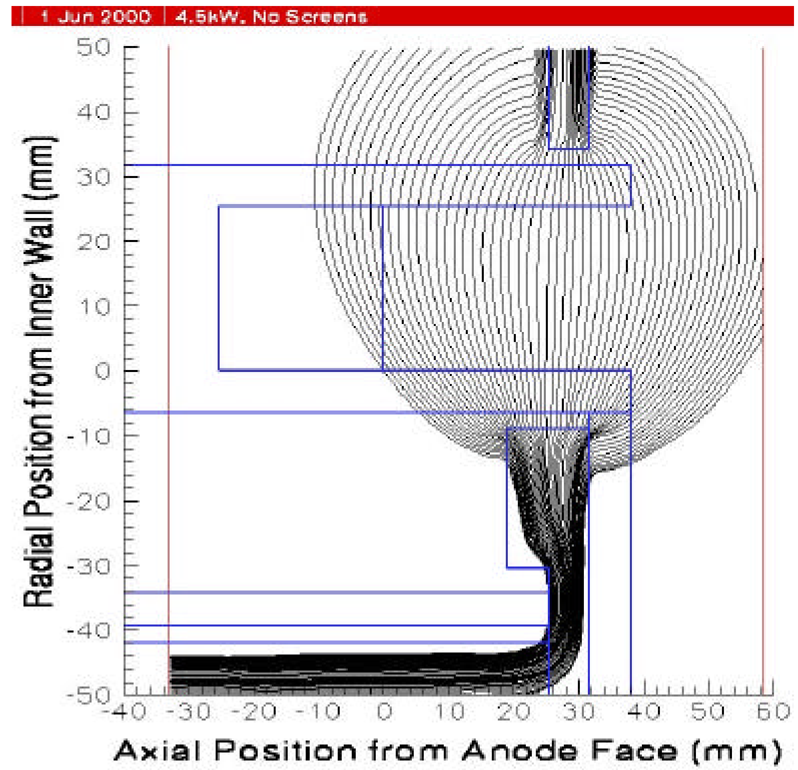


Inner pole chamfer, extended outer pole

Extended Inner Pole and No Magnetic Screens
Magnetic Field Lines



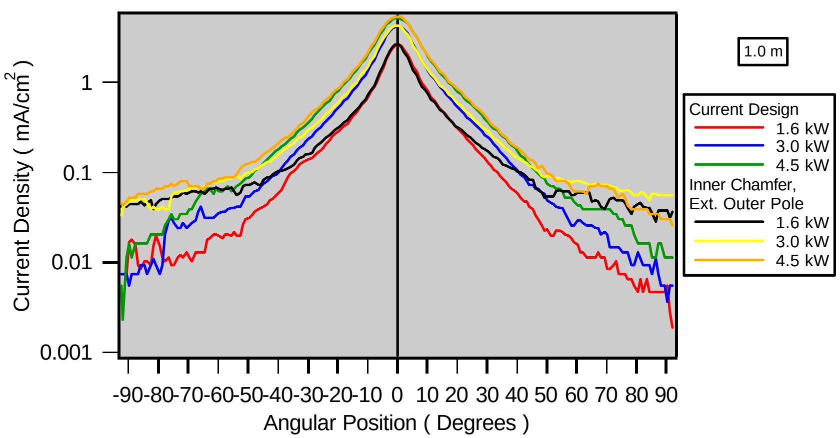
Extended Inner Front Pole



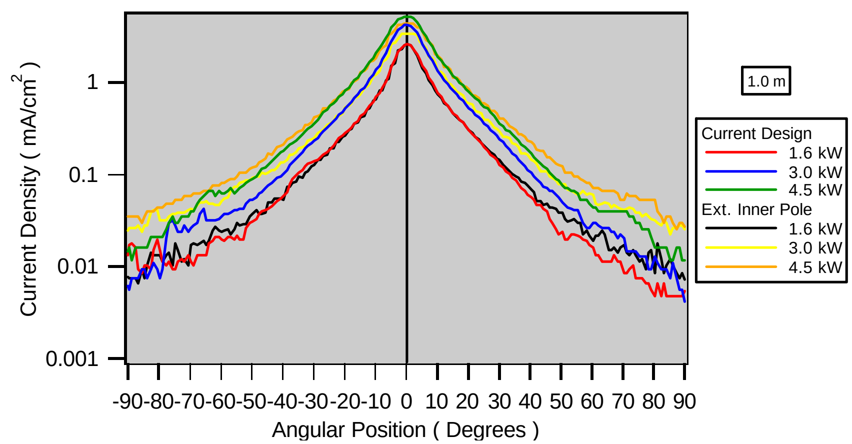
No magnetic screens

Faraday Probe Experimental Results

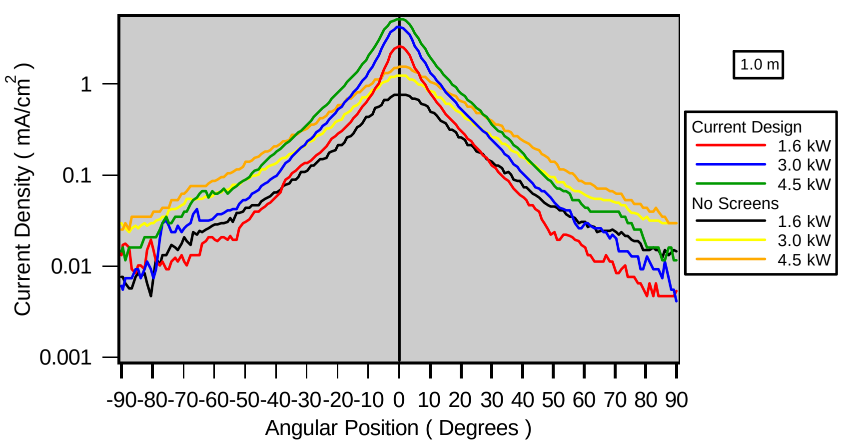
Inner Chamfer, Extended Outer Pole



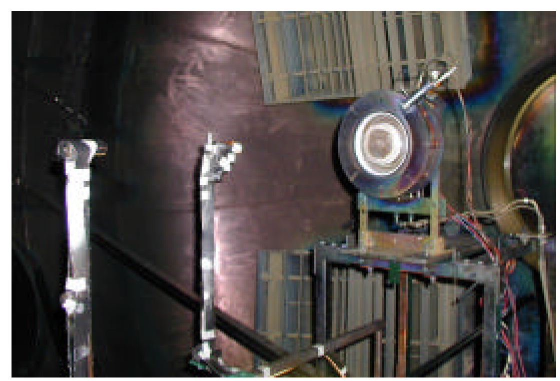
Extended Inner Pole



No Magnetic Screens

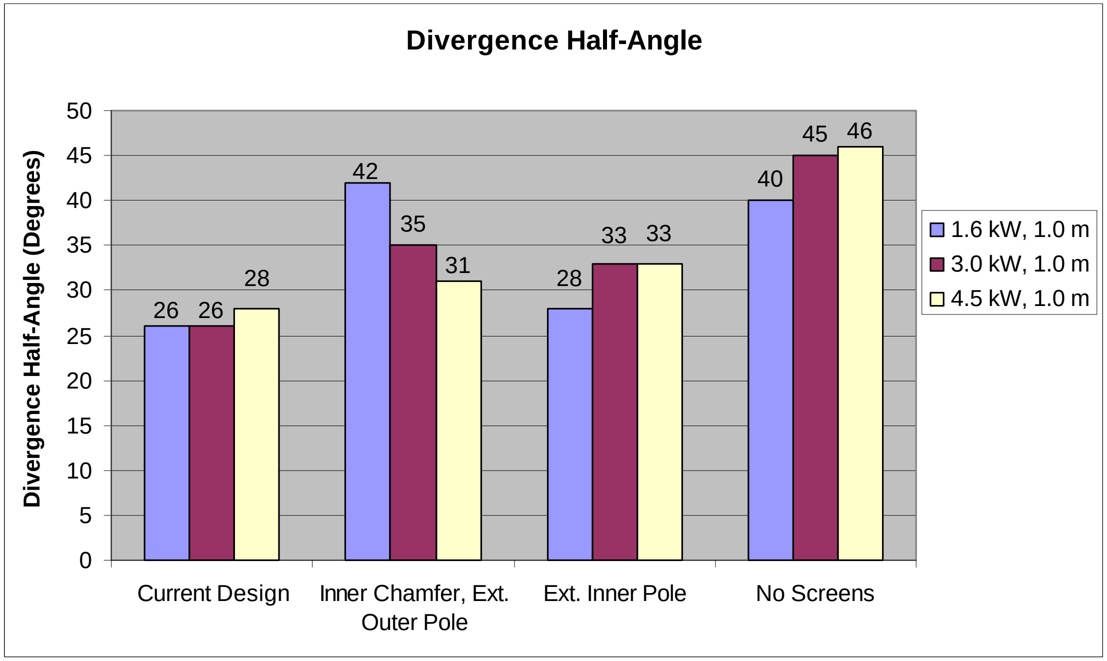


Experimental Set-up



Data collected at z = 1.0 m

Faraday Probe / Divergence Angle



Divergence* Half-Angle (Degrees)

	Current Design	Inner Chamfer, Ext. Outer Pole	Ext. Inner Pole	No Screens	SPT-140**
1.6kW, 1.0m	26	42	28	40	32***
3.0kW, 1.0m	26	35	33	45	28
4.5kW, 1.0m	28	31	33	46	23

*Divergence calculated as 90% of the integrated current between +/- 90 degrees

** Fife, Hargus, Haas, Gallimore, et al, "Spacecraft Interaction Test Results of the High Performance Hall System SPT-140", To be presented at the 36th JPC Huntsville, Alabama. SPT-140 data collected at the University of Michigan.

*** Data taken at 2 kW

- Current design is flat within measurement error of +/- 2^o, and compares favorably with the SPT-140.
- Inner chamfer, extended outer pole appears to be over focused. A decrease in divergence is observed with increasing power, much like the SPT-140.
- Extended inner pole gives slightly higher divergence than the current design. May suggest that slightly divergent B field lines can minimize beam divergence by extending the beam focal point.
- No magnetic screens gave the expected result of poor performance at all power levels.

Conclusions and Future Work

• The current design of the PEPL/AFRL P5 Hall thruster, with pole pieces aligned, resulted in the lowest beam divergence of any configuration and also gave a flat profile with power. Such a profile would be advantageous to a flight model, allowing the thruster to operate safely over a range of power levels. Researchers looking to build simple laboratory models could also use this configuration to minimize cost and complexity.

• Other PEPL data (LIF, MBMS, LP) of the P5 has previously suggested that the focal point of the thruster beam was already within a few centimeters of the exit plane. The resulting beam divergence is thought to be in part due to the beam crossing itself. The use of the convergent field lines here (inner pole chamfer, extended outer front pole) seems to have decreased the focal point further still, as evidenced by increased divergence.

• The above suggested that outwardly focused field lines could actually decrease divergence by extending the focal point. However, the configuration tested in this research did not find a decrease in divergence over the current design. Further testing is planned to examine the use of outwardly focused field lines by considering other designs.

• Magnetic screens have been shown to decrease the divergence of the P5. The symmetry of the screen less configuration results in a broader beam that contributes more current at higher angles than the current design.