The Creation, Analysis, and Verification of a Comprehensive Micro-Ion Thruster Model

Seminar Presentation
Max Bodnar
March 2015
Thesis Goals

• The creation of a comprehensive mathematical model of an ion thruster
  – Included submodels: Physical, Magnetics, Electrostatics, Plasma physics, Power deposition

• Analyze the performance and characteristics of the models
  – Run optimization on the models to identify solutions to the models with increased performance

• Verify the results of the models
  – Use previous theses, NSTAR and NEXT data, and new test data to verify the models and results
MiXI Background

• **MiXI – Miniature Xenon Ion Thruster**
  - Originally developed by Dr. Wirz (UCLA) in 2001
  - CalPoly-V1 created in 2009 for thermal testing
  - CP-V2 created in 2011 for operational testing
  - CP-V3 created in 2012 implemented a hollow cathode tube (current model)
  - Tested for performance by Knapp and for thermal properties during operation by Parker
MiXI Thruster – Physical Model

- Thruster Assembly
  - 3 cm diameter x 3.3 cm tall discharge chamber
  - Contains anode pieces, grids, magnet arrays, mounts, and ceramic isolators

- Hollow Cathode Assembly
  - Barium impregnated tungsten insert
  - Consists of a heater core, graphite keeper, chassis, fuel inlet, and ceramic isolators
Discharge Chamber – Magnetics Model

• Designed in FEMM (Finite Element Method Magnetics)
  – Uses the physical model of from Solidworks to build the edges and points
  – Material properties and magnetic characteristics assigned in FEMM

• 3 Ring-Cusp configuration
  – Attempts to provide two distinct areas within the chamber
    • High strength near cusps
    • Low strength uniform along the center

• Samarium-Cobalt grade 27 magnets
  – 3mm (r) x 1mm (h) disk magnets
  – 11,000 G surface strength
  – 325\(^\circ\) C maximum temperature
Discharge Chamber – Magnetics Model
Discharge Chamber – Magnetics Model

Center line magnetic field strength

MiXI Magnetic Structure

Right edge magnetic field strength

Bottom edge magnetic field strength

Configuration 01: 4o33s

Closed Contour = 368.0406 G
Side Top Cusp = 2920.9845 G
Side Bottom Cusp = 3010.5594 G
Bottom Cusp = 2206.9473 G
Magne(ts Model Configurations

Center line magnetic field strength

MiXI Magnetic Structure

Right edge magnetic field strength

Configuration 02: 4033t

Closed Contour = 177.1627 G
Side Top Cusp = 2979.3005 G
Side Bottom Cusp = 3189.3489 G
Bottom Cusp = 2173.792 G
Magnetics Model Configurations

Center line magnetic field strength

MiXI Magnetic Structure

Right edge magnetic field strength

Bottom edge magnetic field strength

Configuration 45: 213b

Closed Contour = 327.567 G
Side Top Cusp = 2689.3067 G
Side Bottom Cusp = 3184.7893 G
Bottom Cusp = 2124.0654 G
Magnetics Model Configurations

Center line magnetic field strength

MiXi Magnetic Structure

Right edge magnetic field strength

Bottom edge magnetic field strength

Configuration 23: 4i11t

Closed Contour = 184.0389 G
Side Top Cusp = 2418.2779 G
Side Bottom Cusp = 2337.6397 G
Bottom Cusp = 2573.6677 G
Electrostatic Model

- Designed in FEMM (Finite Element Method Magnetics)
  - Uses the physical model of from Solidworks to build the edges and points
  - Material properties and magnetic characteristics assigned in FEMM

- Other stuff about the electrostatics model, this one is much more simple and didn’t vary with configurations, just show sample configuration with the beam potential high
Plasma Physics Model

- Can control only a few inputs to the real thruster, the code was written to emulate that restriction
- Thrusters have throttle points governed by the beam current $I_b$ and mass utilization $\eta_m$
  - This throttle point value is achieved by altering the inputs available to the user: Fuel mass flow, Discharge current $I_d$, and Keeper current $I_k$
  - Performance characteristics can be altered and rely on the physical and electromagnetic configuration (from FEMM)
  - All other values for the plasma model are solved internally
    - Electron temperature $T_{eV}$
    - Plasma potential $\phi$
    - Plasma densities $n_{e,i,0}$
    - Discharge loss $\eta_d$
Plasma Physics Model

• The outputs from Electron Temperature and Plasma Discharge submodels are used in the Power calculations
  – Calculates Thrust, Isp, Beam power, Total power, Electrical efficiency $\eta_e$, Dissipated power, Thrust to power ratio, Total efficiency $\eta_T$

• Plasma physics model set up as input to \texttt{fmincon} in Matlab
  – Able to optimize around any number of variables
  – Used to calculate the optimum solution for a given physical configuration
Plasma Physics Model Output

• Sample output from code and optimizer
• Compare in table the performance characteristics from the previous thesis and what I get from the optimizer
  – Might need to do some work on the optimizer to prevent always pushing the boundaries on some supplies
• Total efficiency, plasma parameters, set points throttle points
Power Deposition – Thermal Model

- Talk about the sinks of power, look at that thermal power paper again,
- Fix thermal code and replicate that table type output with my code and display that here
- Talk about how the output of this code is more of a verification and numbers should match what comes from the plasma model in some points and the power model in others
- Talk about how much of what I was trying to do was reduce the entire thermal load on the system so the thruster can run at steady state since the previous theses had to stop after a few minutes of testing
- Discuss and use the next slide or so to show thermals from Parker
Thermal model output

- My data comparisons
- Tabular output
- Keeping this picture because I might need it for parkers graph

Photo courtesy of Sam Parker
Thermal Test Results - Parker

Photo courtesy of Sam Parker
Testing

• Testing results and comparison with plasma parameters from models and power levels to power code
• More to go here...
• Langmuir testing, some langmuir sweeps and results table comparison of parameters
• Will also want to have a table with differences between configurations that I have data for (currently only 2 😞)
• Results of testing when trying to run optimum code values and comparison to theoretical
Testing still

• Testing stuff
Future work

• More testing and data acquisition
• Compare configurations through tests and code
• Try to get optimal run solution for this thruster
• Maybe try to get maximum thrust/power effect from the thruster if I can and I get ambitious
Summary/Completion of Goals

• Sort of a thesis summary here
• Did I complete the goals I was trying to
• What did I not, what still needs work?