Application of Wall Current Modeling on the Pegasus-III Experiment

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Pegasus-III Experiment

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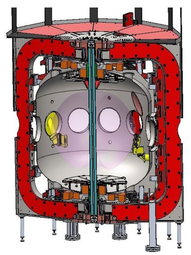
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Wall Current Modeling Is Necessary for Pegasus-III

- The Pegasus-III Experiment explores non-solenoidal startup and heating techniques
- Wall current modeling has been updated for Pegasus-III
  - Aids in coil programming for scenario development
  - Is incorporated into equilibrium reconstruction and analysis
  - Provides insight into where and when LHI begins relaxation
- **Updated wall geometry and calibration provide accurate model for physics studies**

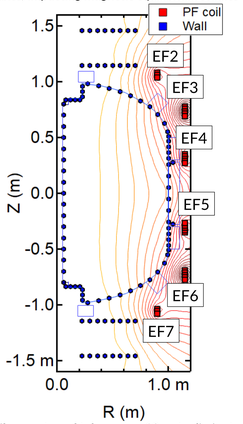
Pegasus-III



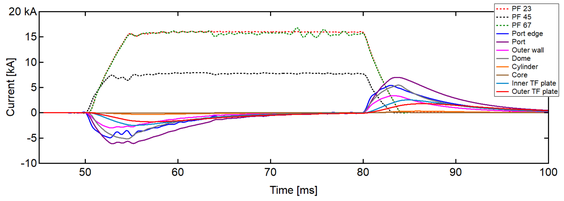
Resistive Wall Introduces Changes to Field

- Pegasus-III vessel is electrically continuous
  - Toroidal currents are induced in vessel wall and core
- Wall current timescales are on the order of pulse timescales
  - Pegasus-III shots are ~20ms
  - Wall current times are ~10ms (τ~3ms)
- Resistive wall introduces changes to driven magnetic field
  - Magnetics diagnostics are sensitive to effects from wall currents
- **Effects from wall currents must be accounted for in analysis**

Wall currents alter the poloidal field and fluxes, impacting magnetic equilibrium studies



Wall currents are on the same order of magnitude as PF coil currents and take up to ~10ms to dissipate. See plot in next section for locations of colored lines.



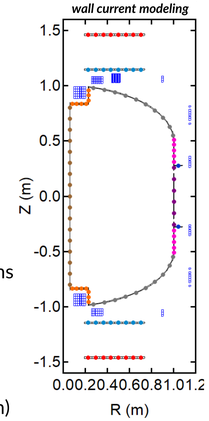
Wall Current Modeling Has Been Updated for Pegasus-III

- The Pegasus-III vessel is modeled as axisymmetric coils for wall current simulation
  - Vessel model has been updated to include structural changes added during upgrade: new core, cylinder, TF support plates
- Inputs
  - Geometric vessel model: 100 wall coils
  - PF currents: ~10 driven coils
- Returns I(t) for each passive wall element from driven PF currents
- Wall currents as a function of time can be determined by integrating the coupled equations for each coil:

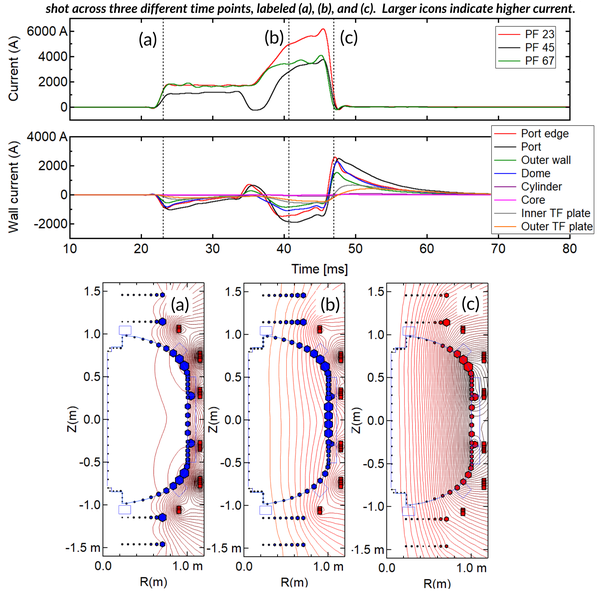
$$\boldsymbol{M}\frac{\boldsymbol{dI}}{\boldsymbol{dt}} + \boldsymbol{R}\cdot\boldsymbol{I} = \boldsymbol{V}$$

M: mutual, self inductance
R: coil resistivity (calibrated parameter)
V: voltage (user input) **I**: coil current(solution)

Toroidally axisymmetric model of the Pegasus-III vessel used for wall current modeling



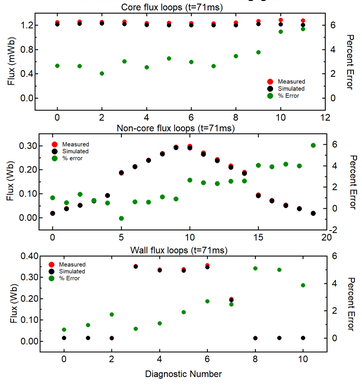
Induced wall currents, fluxes, and corresponding locations on the Pegasus-III device for a vacuum-only shot across three different time points, labeled (a), (b), and (c). Larger icons indicate higher current.



Diagnostic Simulations Show Wall Current Sensitivity

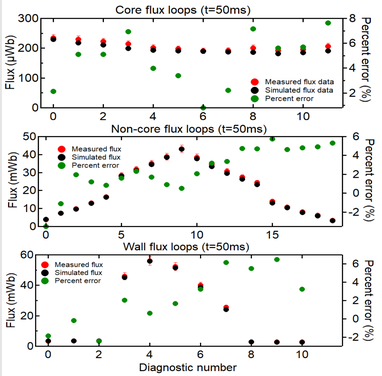
- Pegasus-III features new suite of diagnostics
  - Majority of magnetics diagnostics are accurate to within 5% when wall currents have dissipated

Measurements from diagnostics correspond with simulations when wall current is negligible

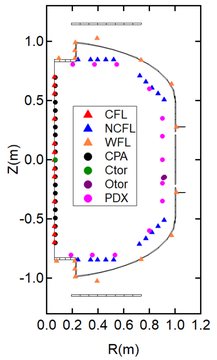


- Vessel material resistivity + semi-empirical calibration used to determine coil resistivities

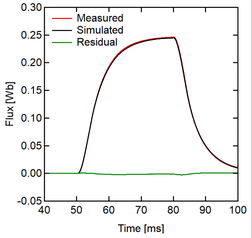
Representative magnetics data and simulated data (vacuum shot)



Locations of magnetics diagnostics

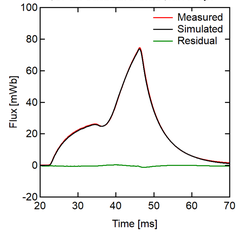


Measured and simulated fluxes for an outboard-side flux loop.



- Calibrated model shows agreement within ~5% for most diagnostics in vacuum shots without full wall current dissipation

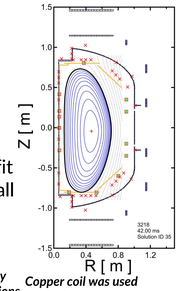
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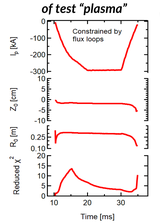
Wall Model Used In: ShapeFIT, KFIT, Null Finder

- New Pegasus-III wall model is used for
  - KFIT equilibrium reconstruction (in progress)
  - ShapeFIT (in progress)
  - Field null finder capabilities (future work)
- KFIT uses wall model to fit plasma equilibrium[2]
  - Incorporates unknown wall currents into fit
  - "Packs" self-similar wall elements—100 wall elements to ~10 packs
- ShapeFIT is a fast-boundary reconstruction code for control room use[3]
  - Preliminary tests show that ShapeFIT successfully recreates centroid location of test "plasma"

KFIT equilibrium reconstruction



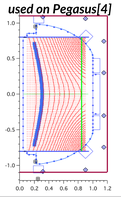
ShapeFIT successfully recreates R and Z locations of test "plasma"



Copper coil was used as test plasma and was held near Z=0cm and R=30cm



Null finder code as used on Pegasus[4]



- Null finder incorporates wall model to find field null[4]
  - Simulates injected current as additional coil to determine field null

Summary and Future Work

- **Wall current modeling has been updated to include new Pegasus-III diagnostics and vessel geometry**
- Wall currents significantly impact plasma shots, which
  - Changes poloidal field
  - Causes pickup in magnetics measurements
- Results from wall current modeling can be applied to
  - Reconstruction analysis
  - Fast-boundary reconstruction
- Future work includes
  - Development of last closed flux surface predictive mode for ShapeFIT
  - Technique to find field null for LHI relaxation

References: [1] A.C. Sontag *et al* 2008 *Nucl. Fusion* **48** 095006; [2] M.W. Bongard (2011) "Edge magnetohydrodynamic instability studies in the Pegasus Toroidal Experiment," Doctoral Dissertation, University of Wisconsin—Madison; [3] J.L. Barr *et al* 2018 *Nucl. Fusion* **58** 076011; [4] J.M. Perry, Preliminary Exam, 2015.

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