Diagnostic Overview for Non-Solenoidal Startup on Pegasus-III

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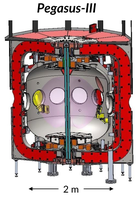
Pegasus-III Experiment

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UNIVERSITY OF WISCONSIN–MADISON

Pegasus-III: A Dedicated Platform for Solenoid-Free Startup

Develop solenoid-free startup in a dedicated facility[1]
- Local Helicity Injection (LHI)[2]
- Coaxial Helicity Injection (CHI: Transient, Sustained)
- RF assist and sustainment (EBW, ECH, ECCD)
- Assess compatibility with RF/NBI heating and current drive

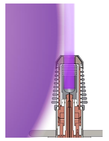
Pegasus-III



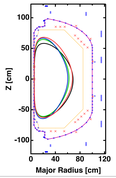
Goal: develop validated physics and technology basis for MA-class startup

Diagnostic Needs for Solenoid-Free Startup Studies

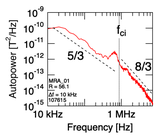
Source & coil feedback control



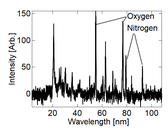
Equilibrium & Kinetic profiles



MHD turbulence & relaxation



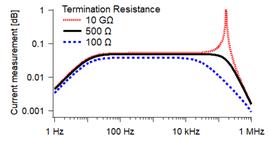
Impurity content



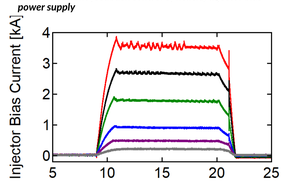
Current feedback actuators in strong EMI environment

Practical considerations for current feedback control with switching power supplies[3]:
- Suppression of EMI from switching transients:
  - Use of shielded twisted-pair connections
  - Proper single-point grounding
- Consideration of Rogowski coil self-inductance, capacitance, and termination resistance
- Characterization of droop correction and drift
- Tuning feedback controller to reduce sensitivity to transients

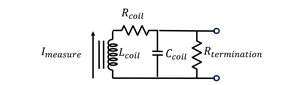
Rogowski coil self-resonance can be mitigated by optimizing termination resistance



Example current feedback control of helicity injector bias power supply



See Poster YP11:31 for details on power supply commissioning

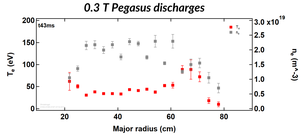


Kinetic Profile Measurements

Helicity injection requires magnetic relaxation
- Heats both ions and electrons
- Localized to the plasma edge
- Results in low inductance plasmas

Motivates core pressure measurements:
- Thomson Scattering
- Interferometry
- Diagnostic Neutral Beam
- Charge Exchange Spectroscopy

Electron density & temperature profiles from 0.3 T Pegasus discharges



- Thompson Scattering laser and spectrometer reinstalled[4,5]
- In-vessel alignment to laser complete
- Rayleigh Scattering calibration complete

See Poster YP:40 for details on Thomson Scattering measurements of recent helicity injection plasmas

288 GHz Interferometer modified to allow for optical alignment with laser

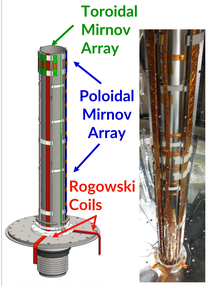


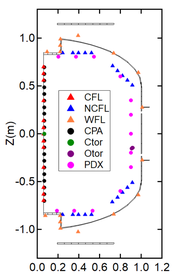
Completed initial design of a spectrometer for majority Charge Exchange Recombination measurements

Fast Ion Gauge measurements for fueling require a line-of-sight baffle to block UV, magnetic shielding, and electrostatic shield to suppress EMI

Internal Magnetics Calibration

New magnetics include co-located flux loops & coils calibrated to better than 1% accuracy



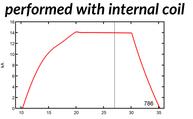


- Signal conditioning designed and calibrated to 10^{-4} accuracy
- Installed 100 flux loops/coils calibrated to 1% accuracy
- Increased number of external flux loops to characterize wall currents
- Wall current model updated to reflect changes to vacuum vessel and additional coil mount structures
- Wall current modelling predicts observed signals from flux loops and coils to within 5%

See poster YP11.39



In-Vessel calibration performed with internal coil



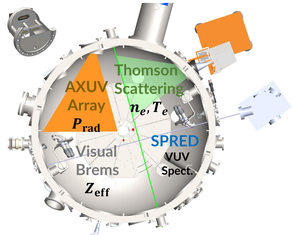
Diagnostic	Number
Rogowski coils	2
Diamagnetic loops	3
Poloidal Mirnov array	34
Toroidal Mirnov array	12
Centerstack flux loops	13
Internal flux loops	20
Wall flux loops	16

Initiated Study of Impurity Impact on Startup

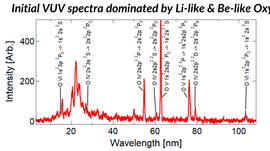
Impurities impact helicity injection:
- Increase resistivity $\eta \propto Z_{\mathrm{eff}} T_e^{-3/2}$
- Radiative cooling increases P_{rad}

Tools to quantify impurities:
- VUV spectroscopy (SPRED)
- Radiometry (AXUV diode array)
- Visual Bremsstrahlung (VB)
- STRAHL transport modelling

Diagnostics used to quantify effects of impurities on helicity injection

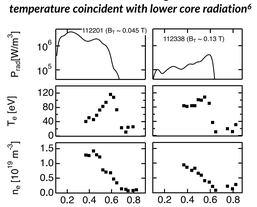


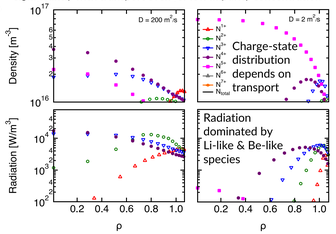
Initial VUV spectra dominated by Li-like & Be-like Oxygen



Impurity transport modelling shows that radiation losses vary significantly with transport even for low impurity concentration

Previous measurements show higher core temperature coincident with lower core radiation[6]



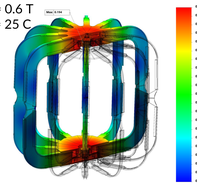


See Talk BO08:6 from Monday for details on impurity transport studies in helicity injection

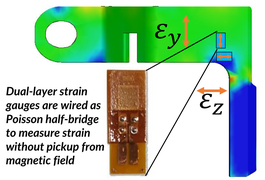
Toroidal Field Coil Strain Monitored

Displacement from thermal & EM forces greatest at centerstack joint[1]

B_T = 0.6 T
T = 25 C



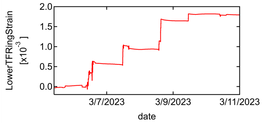
FEM analysis shows we require $1\ m\epsilon$ sensitivity with $100\ \mu\epsilon$ accuracy

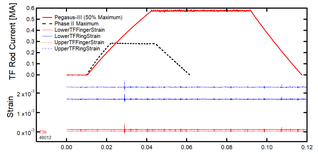


Dual-layer strain gauges are wired as Poisson half-bridge to measure strain without pickup from magnetic field

See Poster YP11:30 for details on TF coil commissioning

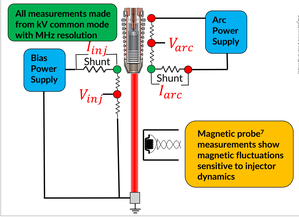
Strain measurements confirmed we reached desired joint compression on assembly with no change in operation



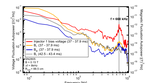


Injector Power Supply Diagnostics

Each 4 MW injector power supply has MHz voltage and current measurements



Injector voltage fluctuations coincident with magnetic fluctuations on same field line



See poster YP11:38 for more information on magnetic turbulence measurements

Cathode Spot Detection & Mitigation

Cathode spot detection system implemented using in vacuuo fiber-coupled optics



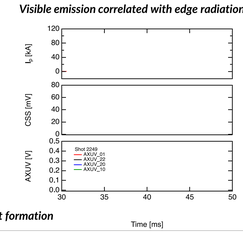


Detection of cathode spot



Cathode spot suppression system requirements:
- Sufficient contrast to distinguish cathode spot from diffuse edge emission
- μs –time response on photodiode detection
- Optical fiber transmission on event detection to crowbar power supply
- Analog output for calibration

Visible emission correlated with edge radiation



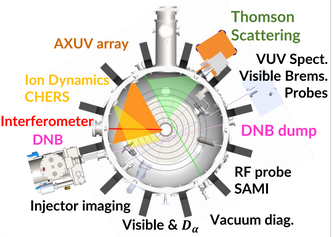
See poster YP11:33 for more information on cathode spot formation

Diagnostics for Non-Solenoidal Startup

Mission-critical requirements:
- Helicity source & coil feedback control
- Kinetic equilibrium reconstruction
- MHD activity associated with relaxation
- Impurity content & transport

Deployed systems:
- EMI-hardened feedback control
- Internal & external magnetics array
- Thomson Scattering (see YP11:40)
- Refurbished VUV & Visible spectroscopy
- Radiometry
- Microwave imaging of EBW emission (see YP11:39 for more information)
- Magnetic probes (see YP11:38)

Under design:
- Charge Exchange Recombination Spectroscopy



References: [1] A.C. Sontag *et al.*, IEEE Trans. Plasma. Sci. (2022), DOI: 10.1109/TPS.2022.3184626; [2] M.W. Bongard *et al.*, Nucl. Fusion **59**, 076003 (2019); [3] M.W. Bongard *et al.*, IEEE Trans. Plasma. Sci. **50**, 4021 (2022) DOI:10.1109/TPS.2022.3165694, [4] Schlossberg *et al.*, Rev. Sci. Instrum. **87**, 11E403 (2016) DOI: 10.1063/1.4962193; [5] Bodner *et al.*, Rev. Sci. Instrum. **87**, 11E523 (2016) DOI: 10.1063/1.4960499; [6] Bodner Phys. Plasmas **28**, 102504 (2021) DOI: 10.1063/5.0054974; [7] Richner *et al.*, Rev. Sci. Instrum. **89**, 10J103 (2018) DOI: 10.1063/1.5036527

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