The New PEGASUS-III Experiment*

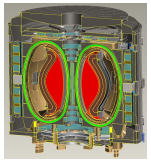
A.C. Sontag, M.W. Bongard, M.T. Borchardt, S.J. Diem, R.J. Fonck, A.K. Keyhani, B.A. Kujak-Ford, B.T. Lewicki, M.D. Nornberg, A.C. Palmer, C. Pierren, J.A. Reusch, A.T. Rhodes, N.J. Richner, C. Rodriguez Sanchez, C.E. Schaefer, J.D. Weberski, and G.R. Winz

University of Wisconsin - Madison

*Work Supported by US DOE grants DE-SC0019008 and DE-SC0020402

Non-Solenoidal Startup is Critical for the Spherical Tokamak- May Benefit Advanced Tokamaks

- Future ST designs call for solenoid-free operation
  - Nuclear STs generally minimize OH due to shielding/cost
- OH solenoid removal simplifies tokamak design
  - Potential cost reduction
  - More space for inboard shielding/blanket → Critical for ST
  - Reduce PF system requirements
  - Lower electromechanical stresses
- Solenoid-free startup techniques may offer tools for modifying $J(R)$



No / small OH HTS ST-FNSF / Pilot Plant

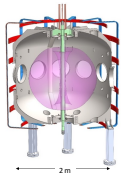
J.E. Menard, Phil. Trans. R. Soc. A 377, 20170440 (2019)

Pegasus-III Will Provide a Dedicated Platform For Solenoid-Free Startup Development

PEGASUS-III Mission: Solve the ST startup plasma challenge by comparing, contrasting and investigating synergistic effects of non-solenoidal current drive techniques using reactor relevant technology

- Compare / contrast / combine concepts for solenoid-free startup in a dedicated facility
  - Local Helicity Injection
  - Coaxial Helicity Injection (Transient, Sustained) – See J. Reusch, Poster Session 121, ID 497
  - RF assist and sustainment (EBW, ECH, ECCD)
  - Assess compatibility with RF/NBI heating and current drive
- Goal: develop validated physics and technology basis for MA-class startup on NSTX-U and beyond

PEGASUS

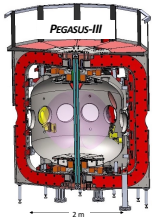


2 m

- **Solenoid-free central column**
- Stronger, high-B_T assembly
- Active divertor coils
- CHI, RF, and next-gen LHI
- Expanded diagnostics

Parameter	PEGASUS	PEGASUS-III
I_{TF}	0.288 MA	1.15 MA
N_{TF}	12	24
ψ_{plat} (mWb)	40	0
R_{Taper} [cm]	5.5	7.0
TF Conductor Area [cm^2]	13.2	72
B_T at R_0=0.4 m [T]	0.15	0.58
B_T Flattop [ms]	25	50-100
A	1.15	1.18

PEGASUS-III



2 m

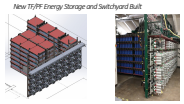
- Significant upgrades are being performed to provide capability for this mission
  - Solenoid removed from system
  - Upgraded/expanded TF power supply and new stored energy
  - **Upgraded TF magnet assembly capable of withstanding forces of 4x higher field**

Poster download available from: https://pegasus.ep.wisc.edu

Expanded Set of Programmable Switching Power Amplifiers to Supply 175 MVA

- Reconfigured switching power amplifiers
  - 32 independent 4 kA 900 V IGBT for magnets
  - Expansion to 40 units planned
- Replaced and expanded stored energy
  - 3 MJ for toroidal field
  - 2 MJ for poloidal field and divertor magnets
  - 2 MJ for LHI arc & bias
- New LHI supply: Multi-level buck converter topology
  - 16 kA at 2.7 kV with sub-ms Vout control
  - 1800 V from slow IGCT system
  - +/- 900 V(t) on fast timescales from corrector
- Fully digital facility timing, control & protection
  - 16 coil set feedback controllers, 15 kHz PID loop rate
  - FPGA-generated timing and triggering
  - Continuous hardware fault protection on < 10 µs timescales
- See M. Bongard, Poster Session 311, ID 481 for more details

New TF/PF Energy Storage and Switchyard Built

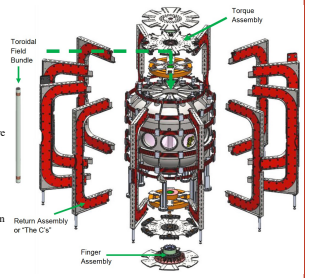


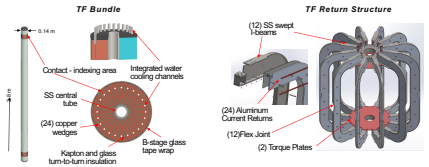
New LHI Arc and Bias Energy Storage and Switchyard Built

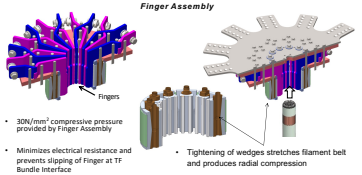


New TF System Consists of 4 Sub-Assemblies

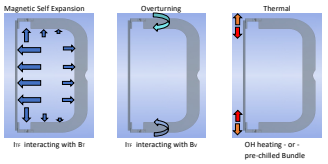
- Torque assembly
  - Plates indexed to vessel
  - Allowed to travel vertically on pins
  - Support divertor coils as well as finger assembly
- TF bundle
  - 24 conductor, water cooled
  - Utilize space from solenoid for more conductor
- TF return structure
  - 12 steel I-beams supporting 2 aluminum conductors each
- Finger assembly
  - Electrical connection between return structure and center bundle
  - Adjacent conductor cross-over eliminates need for back-winding





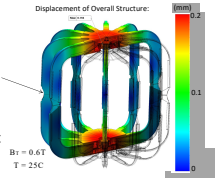


Magnetic and Thermal Forces Present Structural Challenges for Pegasus-III TF Assembly

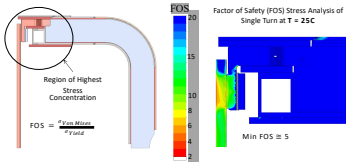


FEM Simulation Allows Load Combination Analysis

- Structure is designed to allow submillimeter displacement
- Semi-Rigid structure opposes magnetic stresses while relieving thermal stresses with outboard flex joint
- Operation temperatures of 10C to 40C analyzed at B_T = 0.6T

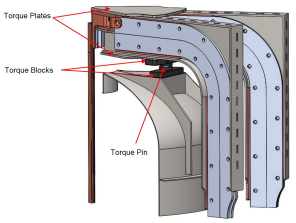


I-Beam Structure and Outboard Flex Joint of TF Returns Reduce Stress to Acceptable Levels



Torque Plate Assemblies Counter Overturning Moment & Transfer Toroidal Forces to Vessel

- Two plates connect all TF I-beams
- Pin attachment to vessel allows vertical motion
  - Pins mount in blocks on vessel & plates
  - Radial and toroidal translation constrained
- Vessel domes reinforced with ribs & gusset plates

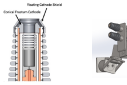


TF Construction Progressing w/ All Major Components In-House

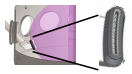


Most Powerful LHI Systems to Date Ready for Install

Two Arrays of 2× 4 cm² Circular Injectors (Twice Area on PEGASUS)



Advanced Non-circular Injector in PEGASUS-III



LHI injector assembly



LHI injector socket



Port mounted injector assembly completed



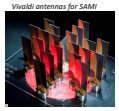
28GHz RF System for EBW/ECH Planned

- Initial RF studies will utilize 28GHz sources
  - 200kW Varian Gyrotron
  - 80kV, 8A power supply
- EBW emission studied with Synthetic Aperture Microwave Imager (SAMI) diagnostic on loan from University of York

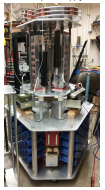
Varian Gyrotron



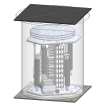
Vivaldi antennas for SAMI



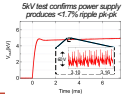
PS based on low ripple 5A, 80kV DNB power supply



HV section of new power supply to be housed in oil bath



5kV test confirms power supply produces <1.7% ripple pk-pk



- *Pegasus-III is poised to expand exploration of fully solenoid-free ST startup to reactor-relevant fields with reactor-appropriate hardware*
- *All major systems well into construction & commissioning – operations to come soon*