The Path to High Field Utilization and Beta in the PEGASUS Toroidal Experiment

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• Stability and confinement at high $\frac{I_p}{I_{tf}}$

• Limits on $q$ and $\frac{I_p}{I_{tf}}$ as $A = 1$
PEGASUS has produced high-$t$, ultralow-$A$ plasmas

Phase I: Achieved Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$</td>
<td>1.15-1.3</td>
</tr>
<tr>
<td>$R$</td>
<td>0.2-0.45 m</td>
</tr>
<tr>
<td>$I_p$</td>
<td>0.16 MA</td>
</tr>
<tr>
<td>$I_p/I_{tf}$</td>
<td>1.07</td>
</tr>
<tr>
<td>$I_N$</td>
<td>$\leq 7$ MA/T-m</td>
</tr>
<tr>
<td>$ RB_t $</td>
<td>$\leq 0.03$ T-m</td>
</tr>
<tr>
<td>$t_{pulse}$</td>
<td>0.01-0.03 s</td>
</tr>
<tr>
<td>$&lt;n_e&gt;$</td>
<td>$1-5 \times 10^{19}$ m$^{-3}$</td>
</tr>
<tr>
<td>$t$</td>
<td>$\leq 25%$</td>
</tr>
<tr>
<td>$N$</td>
<td>$\leq 5%$-T-m/MA</td>
</tr>
</tbody>
</table>

*Vessel Interior*
“Soft limit” of $I_p/I_{tf} \approx 1$ associated with tearing modes

- Limit on $I_p/I_{tf}$ is not abrupt or disruptive

- Resistive MHD instabilities degrade plasma as TF
  - low field + low shear + high $dI_p/dt =$
    rapid growth of tearing modes and large saturated island widths

- Reduced effective V-s as TF also plays a role

- External kinks observed at $q_{95} = 5$

![Sample Data](image)

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Path to high $t$ and $I_p/I_{tf}$: mitigate early MHD

- $I_p > I_{tf}$ regime accessed via suppression of tearing modes
  - Ohmic heating: $I_p > I_{tf}$ high $t$, low $q$

- Approaches and tools to increase $I_p/I_{tf}$
  - Transiently increase $q$ during startup
    \[ = B_t(t) \]
  - Manipulate current profile
    \[ = V_{\text{loop}} \text{ control} \]
    \[ = \text{position/shape control} \]
    \[ = B_t(t) \]
  - Reduce before low-order rationals appear
    \[ = V_{\text{loop}} \text{ control} \]
    \[ = \text{position/shape control} \]
    \[ = \text{RF heating (HHFW)} \]
Overview of PEGASUS Phase II upgrades

- Power supplies replaced - waveform control now available
  - Switching power amplifiers provide waveform control
    = with significant help from the HIT group
  - 6 MJ low voltage electrolytic capacitors installed
  - Stray field “flux catcher” installed for public safety

- Low-inductance toroidal field centerstack installed
  - Provides time-variable TF
  - Maximum $B_t$ increased 3x
  - New TF joint structures implemented

- Lab infrastructure improved or replaced
  - Lab completely rebuilt from “green field”
  - Screen room installed for control and data acquisition
  - New control system and code implemented

ABB IGCT
2.8kV@4kA
Steady-State
~ 50 cm long

Partially assembled TF joints

QP1.068 - Quinn et al.
QP1.069 - Burke et al.
TSC simulations used to guide exploitation of new capabilities

- TSC model developed for PEGASUS
  - Realistic constraints on coils
  - Detailed wall model
  - Reasonable match to Phase I fiducial plasma

- Initial simulations $I_p \sim 0.3$ MA
  - $dI_p/dt = 20$ MA/s
  - All coils within PS limits
  - Stored energy increased 4x over 0.15 MA fiducial
  - Flux swing of 85 mWb matches expectations

- Fast TF rampdown also modeled
  - Provides access to higher $t$
  - Generation of significant $J_{edge}$ and $I_p$

QP1.067 - Eidietis et al.
Stable equilibria exist at $l_p/l_{tf} \approx 2$

- DCON used to evaluate stability of high $l_p/l_{tf}$
- Initial studies: equilibria with $l_p/l_{tf} > 3$ stable to all modes except resistive interchange
- Further studies to include effects of:
  - Finite beta
  - Diverted configuration
  - Edge currents

### Equilibrium Parameters

- $I_p = 0.29$ MA
- $I_N = 12$ MA/m-T
- $l_p/l_{tf} = 1.93$
- $I_i = 0.59$
- $q_0 = 1.5$
- $R_0 = 0.39$ m
- $a = 0.34$ m
- $A = 1.15$
- $q_{95} = 4.8$

### DCON Output

- ArcSinh $D_1$ (A.U.)
- ArcSinh $D_R$ (A.U.)
- Mercier
- GGJ
- Crit

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Capacitor banks installed in outside vault
Laboratory reconfiguration is complete
Low power operations have begun

- Currently
  - First power put through new TF coil
  - EF coil packs tested to 15 KA
  - EF buswork improvements implemented

- November-December
  - Continue power / stress / cross-field testing

- December-January
  - Begin deployment of high-power switches
  - Possible low-power plasma ops with hybrid power supplies

- December-February
  - Deployment and testing of high-power programmable power supplies

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Summary

• **PEGSUS** is an ultra-low A ST with a mission to explore plasma limits as $A \approx 1$

• Phase I of plasma operations has demonstrated high $t$ and $I_p = I_{tf}$ ohmically

• Upgrades will increase experimental flexibility and power

• Initial simulations using TSC and DCON indicate a path to stable, high $I_p/I_{tf}$ equilibria

• Lab reconfiguration is complete and power testing has begun
PEGASUS poster presentations on Thursday morning

QP1.066 - Unterberg
Low-q Operation in an Ultra-Low-Aspect-Ratio Torus

QP1.067 - Eidietis
Modeling PEGASUS Plasmas with TSC

QP1.068 - Quinn
PEGASUS Facility Upgrades

QP1.069 - Burke
Upgraded Diagnostics and Control Systems for the PEGASUS Toroidal Experiment