Abstract

The operational space of the PEGASUS Toroidal Experiment will be significantly expanded by recent upgrades: shape and position control, increased and time variable toroidal field, increased ohmic flux, and loop voltage control. The Tokamak Simulation Code (TSC)\textsuperscript{1} is used to model plasma evolution in a number of scenarios in order to determine accessible paths to high $I_p/I_{TF}$ and $\ell_t$. Various startup scenarios and fast toroidal field rampdown are under study. The focus of the startup studies is optimization of the loop voltage waveform and plasma position during the current ramp. Fast TF rampdown is a tool that may allow access to high $I_p/I_{TF}$ and $\ell_t$, but which could have deleterious effects on stability if overdriven. Initial studies show that a 50\% TF rampdown in 3 ms increases $\ell_t$ by a factor of 4 while keeping $\ell_p$ relatively constant, and drives parallel edge current that reduces $\ell_i$ and $q_{95}$.


* Supported by U.S. D.O.E. Grant DE-FG02-96ER54375

** The research was performed under appointment to the Fusion Energy Sciences Fellowship Program administered by Oak Ridge Institute for Science and Education under a contract between the U.S. Department of Energy and the Oak Ridge Associated Universities.
Motivation

• The PEGASUS Toroidal Experiment has undergone significant upgrades to power and control systems\(^1\).

• Phase II goals include:
  
  – \(I_p\) up to \(\sim 0.3\) MA
  – \(I_p/I_{TF}\) > 2
  – High \(b_{Tor}\)
  – Extremely Low Aspect Ratio (1.1)

• Preliminary TSC studies begun to explore viable paths

\(^1\) See posters: QP1.068, QP1.069
Outline

1. Building PEGASUS TSC Model

2. Discharge Simulation Using Enhanced OH and EF Capabilities

3. Simulation of Toroidal Field Rampdown Using Enhanced TF Capabilities

4. Conclusions
Building PEGASUS TSC Model
Overview: Tokamak Simulation Code

- Models evolution of axisymmetric tokamak plasma on several time scales

- Circuit equations, effects of induced currents in conducting walls included

- Arbitrary transport model (Coppi-Tang used for this study)

- Realistic feedback control system modeling

---

Establishing PEGASUS TSC Model

- Walls & coils modeled as discrete coils
  - Continuous conducting wall

- Z symmetry assumed

- Calibration to shot #13064:
  1. Preprogrammed actual OH, EF, TF currents
  2. Compared macroscopic plasma properties at peak Ip (t = 20ms)
  3. Primary interest in matching Ip evolution
Comparison of Actual to Simulated Plasma Parameters

- Achieve similar maximum $I_p$ on equivalent time scales

Shot 13064

TSC Simulation

- Internal energy, $\ell_1$ both within $\sim 20\%$ actual values at $t = 20\text{ms}$

- Maximum $T_e \sim 200\text{ keV}$, near estimates
Enhanced Discharge Simulation
Enhanced PEGASUS Capabilities

- Upgraded OH power systems provide:
  - Improved OH waveform control
  - Increased V-s

- PEGASUS capable of $I_p \sim 0.3 \text{ MA}$

- Upgraded EF power systems provide:
  - Improved EF waveform control
  - Independently controlled coilsets

- Larger, shaped plasmas accessible

- Use TSC simulations to guide exploitation of these new tools
TSC: 300 kA $I_p$ Achievable with Available V-sec

- TSC shows 0.3 MA ramp in 12ms
- $B = 0.15$ T
- Required ohmic waveform within capability of new power system
Larger Plasmas Accessible

- Flexible EF coils and power supplies should provide greater plasma size control
  - Previously restricted to $R_0 < 0.35 \text{ m}$
  - $R_0 \sim 0.40$-0.45m allows access to lowest $A \sim 1.14$
Sample Plasma Properties

- $V_{\text{vac}} \sim 15\%$ predicted at $B \sim 2x$ typical

- Loop Voltage

- Internal energy
  - Increased $4x$ over Phase I reference shot
Current Profile

- Current profile typical of ohmic plasma
- Maximum $\ell_i \sim 0.7$
• $q_{0\text{min}} \sim 0.8$

• $q_{95} > 3$ throughout shot
EF Coils Within Design Parameters

• Design: All EF coils up to 20kA/turn
$B_{TOR}$ Rampdown Simulation
Toroidal Field Rampdown

• Rapid $B_{\text{Tor}}$ rampdown at high $I_p$ allows access to:
  
  – $I_p/I_{\text{TF}} > 2$
  
  – High $B_{\text{Tor}}$

with internal MHD suppression at startup

• Two enhancements now enable PEGASUS to ramp down:
  
  – Low-inductance TF coils
  
  – Better TF current waveform control
TF, $I_p$ Current Evolution

- TF rod current ramped down 300-150 kA in 3 ms

- Rampdown coincides with $I_p$ peak
  - Drives ~ 50 kA $I_p$

- $I_p/I_{TF} > 2$ achieved
Tor and q Evolution

- Significant increase in \( \text{Tor} \) from rampdown (e.g. 15-40%)

- For these initial simulations, \( q_{95} \) falls below 3
  
  - Further manipulation of plasma shape may be required
  
  - Divertor coils not activated
  
  - Necessary to cross-compare with DCON equilibria to explore avenues to accessibility\(^1\)

\(^1\) See poster QP1.066

N.W. Eidietis, APS-DDP, Albuquerque, N.M., October 2003
Plasma Current Profile

- Broadened $I_p$ profile during rampdown causes $\ell_i$ to drop
  - Current driven at edge
Shaping Due to Rampdown

- Rampdown increases elongation
Conclusions

• Initial TSC model for PEGASUS established
  – *Useful to guide exploitation of new experimental capabilities*

• Initial TSC simulations indicate Phase II PEGASUS able to achieve:
  – $I_p$ up to $\sim 0.3$ MA
  – $R_0 > 40$ cm
  – $I_p/I_{TF} > 2$ via Toroidal Field Rampdown
  – Increased $B_{tor}$ via Toroidal Field Rampdown