

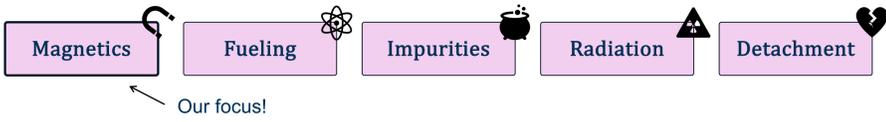
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Overview

What is plasma control?

- Reliable plasma control systems (PCS) are needed to operate, sustain, and reproduce high-performance tokamak plasma scenarios [1].
- In real-time, the PCS monitors:



Why are we interested?

- Designing new scenarios and magnetic controllers requires experimental trial and error.
- In silico* testing avoids wasting (expensive) experimental runtime!
- Very few open-source frameworks for plasma scenario design [2].

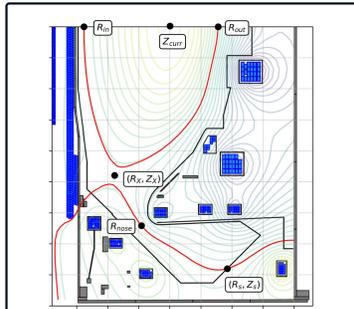


Fig 1: Poloidal cross-section of MAST-U showing shape parameters.

What have we done?

- Developed the FreeGSNKE Pulse Design Tool (FPDT) [3].
- Validated it against past MAST-U shots.
- Open-sourcing it very soon!

Validation against MAST-U discharges

MAST-U shot 50366:

- Ohmically heated, I_p (~750 kA), double-null, X-point target divertor.
- Initial condition built using EFIT++ reconstruction data.
- Same PCS setup as real shot.
- Simulate flat-top phase only.
- Three simulation modes (see paper for more details):
 - Nonlinear (NL).
 - Piecewise linear (PwL).
 - Piecewise linear dynamics (PwLD).
- Excellent agreement with experiment and waveforms.

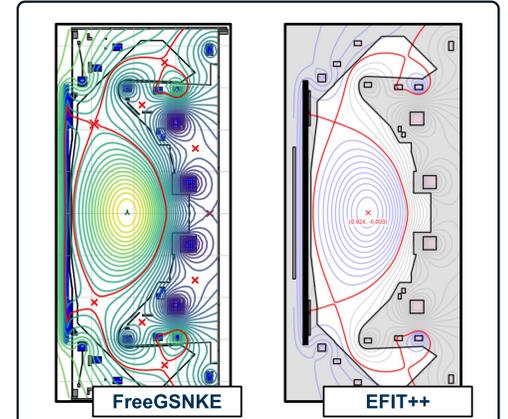


Fig. 2: Simulated plasma equilibria at time $t = 0.5s$.

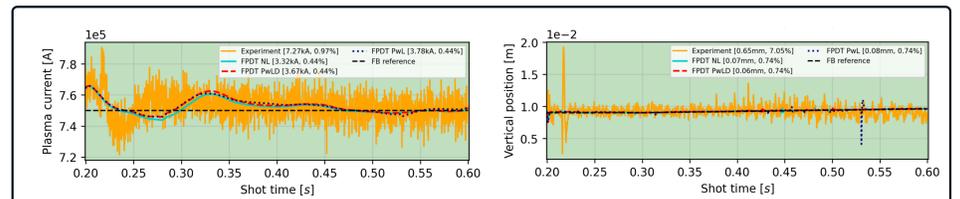
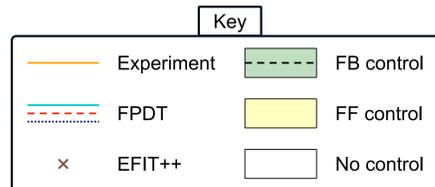


Fig. 3: Evolution of plasma current I_p (left panel) and vertical position Z_{curr} (right panel).

FreeGSNKE Pulse Design Tool

What is it?

- Combines FreeGSNKE evolutive equilibrium simulator [4] and a new modular, customisable virtual PCS.
- Foundation for future plasma "flight simulators".



What can it do?

- In advance of experiments, one can:
 - Design challenging plasma scenarios ✓
 - Test and calibrate new control algorithms/settings ✓
 - Assess whether a scenario violates machine safety limits ✓
- Initialise using your own tokamak and PCS structure.
- Integrate seamlessly with AI/ML libraries.

How does it work?

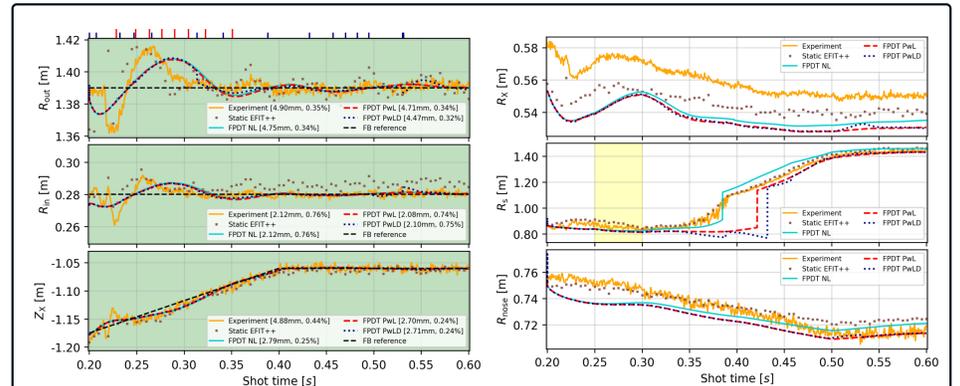
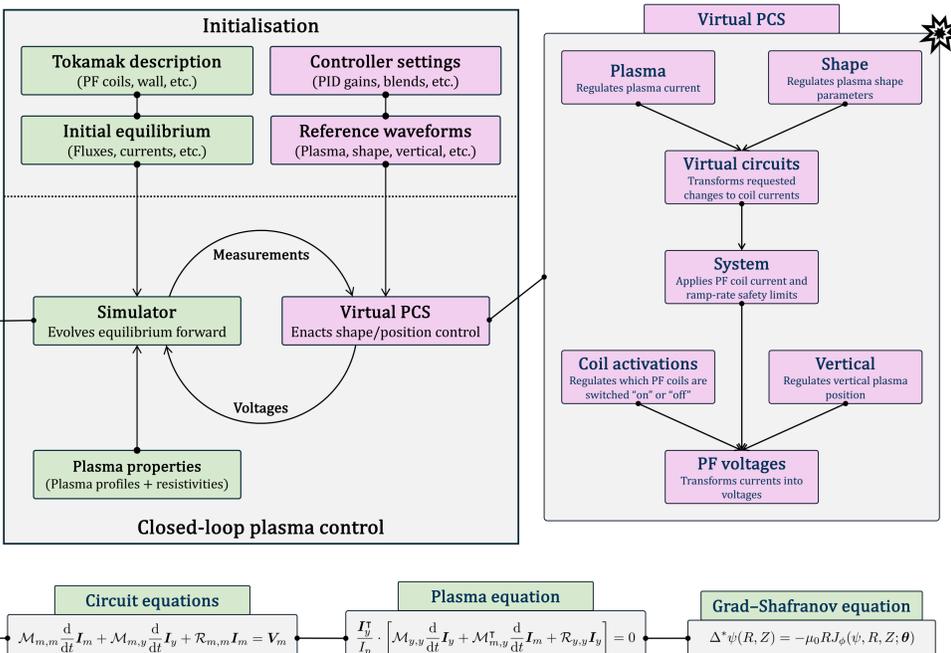


Fig. 4: Evolution of six shape parameters over time (refer to Fig. 1).

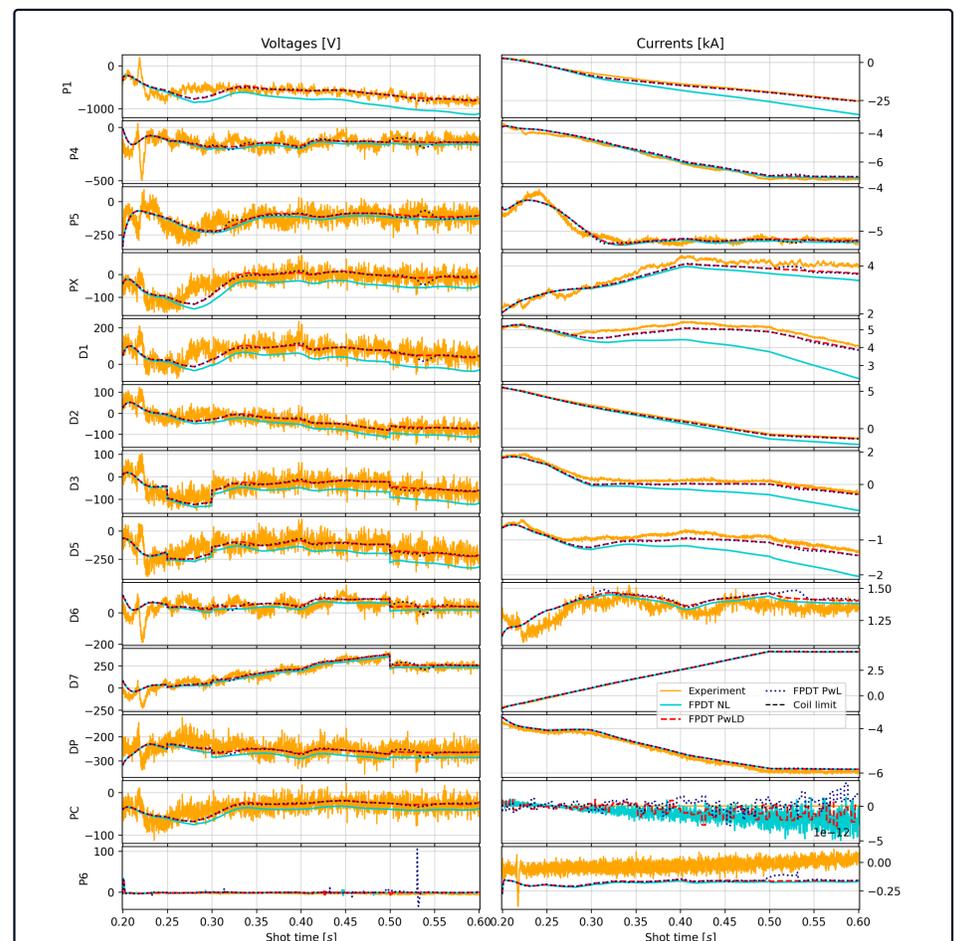


Fig. 5: Evolution of the poloidal field coil voltages (left panels) and currents (right panels) over time.

References and ongoing projects

- M. Ariola and A. Pironti, *Advances in Industrial Control*, 2016. DOI:10.1007/978-3-319-29890-0.
- NICE, 2025. Available at: <https://gitlab.inria.fr/bfaufer/nice>.
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- N. C. Amorisco et al., *Phys. Plasmas*, 2024. DOI: 10.1063/5.0188467.
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- Coupling to current diffusion equation (in progress)
- Validating JAX-based internal solvers (in progress)
- Virtual circuit emulation validation (papers incoming)