EPFL

PHYS-748

Control and Operation of Tokamaks

Felici Federico, Galperti Cristian, Mele Adriano, Merle Antoine, Pau Alessandro, Reimerdes Holger

Cursus	Sem.	Type
Physics		Opt.

Language of teaching	English
Credits	3
Session	
Exam	Oral
Workload	90h
Hours	**50**
Lecture	32
Exercises	18
Number of positions	**40**

Frequency

Every 2 years

Remark

Next time: Spring 2025

Summary

This course treats the main issues in operation and control of a tokamak. Control-oriented models are derived and controllers are designed using techniques from modern control theory. Operational limits are discussed as well as state-of-the-art research questions for future reactors.

Content

Tokamaks represent one of the prime candidates for a commercially viable nuclear fusion reactor design. Several tokamaks are being operated around the world to study fusion-relevant plasmas, including the TCV tokamak at EPFL. A key challenge to enable physics studies of plasmas is to be able to effectively operate present-day tokamaks and control the plasma properties as desired. In addition, control issues will be critical for future devices which will have to operate close to operational limits while maintaining a stable plasma at all times.

During this course, students will familiarize themselves with key concepts of control & operations of tokamaks.

The course will cover the following topics:

Axisymmetric equilibrium control:
* Axisymmetric magnetic equilibrium: fundamental equations, modeling and rigid-plasma model
* Basic controller design for tokamak magnetic control: position and current control, shape control
* Equilibrium codes and their role in tokamak operations: Grad-Shafranov equation and its linearization, equilibrium reconstruction, inverse tokamak equilibrium problem.
* Tokamak discharge evolution from breakdown to ramp-down.

Kinetic, MHD and heat flux control:
* Kinetic control: review of key equations describing the evolution of plasma core temperature, particle density, and current density profiles and their consequence for tokamak discharge evolution.
* Review of tokamak actuators and their role in control.
* State observers for kinetic profiles, optimization methods for core performance optimization.
* MHD limits and their consequences for tokamak operation & control. Control of NTMs and Sawteeth. Basic ELM types and relations to pedestal limits. Basics of ELM suppression and avoidance.
* Plasma-wall interaction and its relation to operational constraints.

Technology:
* Technological requirements and solutions for present-day and future tokamaks. ADC/DACs, real-time networks,

real-time computing. Real-time algorithm concepts. Visit of the TCV tokamak with emphasis on its control systems.

'Hot' and/or emerging Topics
* Discharge monitoring, supervision, off-normal event handling, disruption avoidance & mitigation triggering.
* Model-based controller design and testing: the role of whole-device modeling and flight simulators.
* Machine Learning and its role in tokamak operations & control.

The course is given in intensive format over two weeks. The first week will be a mix of lectures and hands-on exercises, where students will be tasked to design their own tokamak controllers. The students will have the opportunity to work with state-of-the-art tokamak control and simulation tools developed at SPC to tackle a variety of problems. Live, full-time attendance to the first week is expected from all participants in the course. The second week will feature lectures on advanced topics, and the students will have more time to work on the exercise sets. Students traveling to EPFL for the first week can optionally attend the lectures in the second week remotely.

An oral exam will be held at the end of the second week for students wishing to obtain credits.

Note

Invited lecturer: Dr. Federico Felici (Google DeepMind, email: ffelici@google.com)
Dates: MON 03.02.25 to FRI 14.02.25 (block course)

Keywords

Tokamaks, MHD, model-based control, control engineering, state estimation, machine learning

Learning Prerequisites

Recommended courses

Highly recommended: BSc-level knowledge in control engineering and electromagnetism.
Recommended: Some previous exposure to plasma physics and basic understanding of tokamaks.

Learning Outcomes

By the end of the course, the student must be able to:

- To describe the main control loops in tokamaks, the sensors and actuators, the control- oriented models governing the dynamics of the system, and to design simple feedback controllers using tools from modern control theory.

Resources

Moodle Link

- https://go.epfl.ch/PHYS-748