

EDPY – 734 Control and operation of tokamaks – Optional Oral Exam

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Exam rules

- You may bring 1 single-sided, A4 paper with *hand-written* notes into the exam room. These notes may be inspected before the start of the exam to check that they comply with these rules.
- The exam will last 30 minutes.
- During the exam:
 - You will draw 2 questions, one from the set of questions (1)-(4), and one from the set (5)-(7) below.
 - These questions will serve as starting point for a discussion to probe your knowledge and understanding of the subject.
 - For questions involving models and equations, we expect you to provide a sketch of the derivation on the board.
- The final grade for the course will simply be *pass* or *fail*. Upon request a grade indication between 1 and 6 will be provided for information only.
- Passing the exam grants 2 ECTS

List of exam questions

Rigid modeling and magnetic control of plasmas

- 1) Derive an electromagnetic model for currents in the tokamak PF coils + vacuum vessel, outline how the vessel current dynamics can be modeled using an eigenmode representation and how this helps to reduce the model size. Explain how the current in PF coils can be feedback controlled and derive a simple controller that gives zero steady-state error.
- 2) Explain two ways in which the plasma current and position can be determined by a linear combination of magnetic field measurements around the tokamak. Also show how the plasma current can be controlled and derive a simple controller for the plasma current by acting on the OH coil.
- 3) Explain the main assumptions made when modeling the plasma as a rigid body. Sketch the main aspects of the derivation of the RZIP model of a tokamak plasma. Explain how the Nyquist criterium can be used to determine controller parameters appropriate for stabilizing the vertical position instability.

Grad-Shafranov equilibrium

- 4) Explain the role of the Grad-Shafranov equation and give a sketch of the derivation. Describe three possible uses of a GS equation solver, and the role of each in tokamak shot preparation and control. Explain which constraints and cost function terms are used to calculate the required PF coils to sustain a plasma equilibrium using in the FBT code.

Plasma instabilities

- 5) List three plasma instabilities that limit the performance of a tokamak plasma. Explain how the Modified Rutherford Equation describes the evolution of a Neoclassical Tearing mode. Explain why NTMs are 'metastable' and how ECCD can be used to stabilize the mode.

0D tokamak kinetic modeling and control

- 6) Outline the derivation of a 0D power balance model for a tokamak plasma, explain the main power sources and sinks. Sketch the procedure to derive a controller for the plasma beta based on a linearization of the model. Describe 2 diagnostics and 2 actuators used for plasma kinetic control.

1D plasma profile modeling and control

- 7) Sketch the derivation of the poloidal flux diffusion equation, and explain the main terms. Describe the following limit solutions for the flux diffusion equation:
 - fully ohmic plasma with stationary current density profile.
 - fully non-inductively driven, steady-state plasma.