A control system for suppression of magnetic islands in a fusion plasma

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1 Introduction

A real-time control system is introduced, which is designed for the stabilization of magneto-hydrodynamic (MHD) events in a present-day experimental fusion reactor, i.e. a so-called tokamak. In the torus-shaped tokamak, a plasma is confined magnetically using helical magnetic fields. The control system presented here, focuses on the suppression of so-called magnetic islands, encountered in such plasmas [1]. Actively controlled suppression is required since these events harm the operational stability of the machine and deteriorate the plasma performance.

2 Suppression of magnetic islands

High power electron cyclotron waves (ECRH or microwaves) are recognized as an ideal tool for control of plasma profiles and instabilities, like magnetic islands, where one exploits their effect on the plasma in terms of localized heating and current drive. Deposition of the ECRH power onto the magnetic instability must be performed precisely within certain accuracy. Misalignment of the ECRH power deposition w.r.t. the magnetic island reduces the effectiveness of its suppression. An island track-and-kill system must therefore deal both with the identification of the magnetic island and its position in the plasma, as well as with the steering of the ECRH beam in order to deposit the power at the magnetic island. Note that such system has a typical feedback control structure where the necessary detection and control actions must be performed in real-time within tenth of milliseconds, while the tracking of the ECRH wave beam w.r.t. the island is subject to disturbances.

3 Real-time control system

The particular control system discussed here is designed and implemented at the TEXTOR tokamak, Forschungszentrum Jülich, Germany. The TEXTOR installation involves a 800 kW source, which produces a 140 GHz ECRH wave beam. This beam can be directed at any location within the plasma by a fast steerable mechanical launcher. Model-based position controllers have been developed and implemented for this launcher, based on analysis of its dynamics. Identification of magnetic islands relies on the perturbations caused by their appearance on the magnetic topology and the electron temperature profiles of a plasma. Plasma diagnostics like electron cyclotron emission (ECE) and Mirnov coils are used to identify the magnetic islands. On TEXTOR, the tasks of instability identification and localization and of the steering of the ECRH wave beam are combined in a single system, in which low power (100 pW) Electron Cyclotron Emission is measured along the same sight-line as the high power (800 kW) ECRH wave beam [2]. The ECE spectrum is measured while scanning the combined ECRH/ECE wave beam through the plasma. Localization of a given structure in the ECE spectrum relative to the ECRH frequency is thereby used directly to position the ECRH power relative to this structure. Algorithms to extract relevant control variables such as the location, amplitude and phase of the magnetic island from these fluctuation measurements will be addressed. The generation of control set-points for the launcher steering and control of the ECRH power will be demonstrated. A flexible real-time control and data-acquisition system is currently installed for implementation of the data-processing algorithms, trajectory generation and for real-time execution of the control loops.

4 Model-based control design and experimental validation

The design of controllers for this control problem is aided by the development of a dedicated simulation model of the overall control loop, including magnetic island and plasma dynamics, actuator models, diagnostic models, and models for the data-processing algorithms. A complete control simulation for typical TEXTOR conditions is in progress. Experimental results are used to validate and optimize the functionality of the control system to guarantee stable, accurate and fast positioning of the ECRH wave beam.

References