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Real-time diagnostics at ASDEX Upgrade—Integration with MHD feedback control

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Abstract

At the ASDEX Upgrade tokamak experiment, a new feedback control loop is under construction with the aim of stabilizing magneto-hydrodynamic (MHD) instabilities, such as neoclassical tearing modes and sawteeth. It uses the mirrors of the electron cyclotron heating (ECH) launchers, which can be steered in real-time to guide each beam to the position needed to stabilize and suppress the mode.

The control system needs highly specialized plasma state information such as island position and ECH beam deposition locations in real-time. Data from several diagnostic systems, like electron cyclotron emission (ECE), magnetic measurements and motional Stark effect must be combined in real-time to obtain the required information. These systems strongly differ in sampling characteristics and time resolutions. High sampling rates as 2 MHz for ECE are often required to provide enough data for correlation or frequency analysis. On the other hand, complex analysis methods, such as equilibrium and profile reconstruction, may operate on slower rates of some milliseconds and need tight interaction with measurement systems and high computing power.

In this paper, we describe a concept for distributed real-time diagnostic data handling, integration of data from several asynchronous diagnostic systems, and connection to the discharge control system for a broad spectrum of requirements. The system is structured into distributed diagnostic computer clusters, a real-time signal server to combine all information, and the discharge control system. While the focus is currently on MHD control, further real-time diagnostic related applications will be added in future.

Keywords: Real-time diagnostic; Control system; MHD stabilization; ECH

1. Introduction

The impact of magneto-hydrodynamic (MHD) instabilities in the plasma core is so important that sufficient performance can only be achieved, if these instabilities are actively controlled. Overviews of the stabilization of MHD modes and the feedback concept planned for ASDEX Upgrade are described in [1,2], respectively. In summary, the presence of a mode in the plasma flattens the temperature profile, which is measured by the electron cyclotron emission (ECE). It produces fluctuations in the toroidal symmetry of the poloidal magnetic field, which can be detected by Mirnov coils. Further magnetic flux and field measurements, together with polarization angles measured using the motional Stark effect (MSE), allow to reconstruct the internal magnetic plasma structure and to map all information to a common coordinate system. From these raw measurements one can extract the physical quantities of interest: the mode's location, size and amplitude. Fig. 1 shows, how the magnetic flux surfaces link island position, ECE observation channels and ECH beam deposition and illustrates the necessity of combined diagnostic evaluation. With this information the controller directs the beams of the electron cyclotron heating (ECH) to the resonant flux surface, where the mode is located, by moving the steerable mirrors [3]. There, by depositing power and driving current, the

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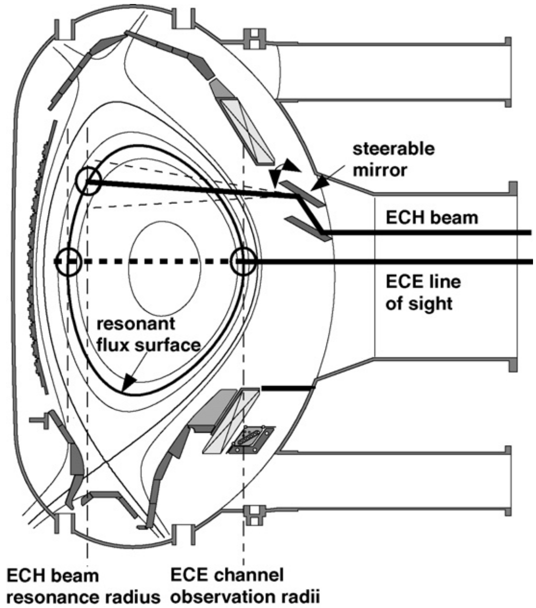

Fig. 1. MHD control principle.

mode is stabilized. Fig. 2 shows the resulting control loop. MHD control is supposed to become a permanently available tool also in standard plasma operation and is planned also for ITER.

All methods require the combined evaluation of several multi-channel diagnostic systems, executing analysis algorithms of considerable complexity and a prompt and accurate reaction of the actuator, computed by the discharge control system (DCS) [4]. The key challenge is to integrate diagnostic systems with the control system in real-time. The basic idea – sharing diagnostic data over a real-time data network – is common to many other fusion devices like DIII-D [5], JET [6] and JT60 [7]. The details, however, vary according to the control system philosophy and networking hardware. Our approach comprises several steps: adding real-time capabilities and preprocessing algorithms to diagnostic systems (Section 2), defining a software framework for integration of diagnostic data from asynchronous sources (Section 3), implementing this framework on a real-time signal server with connection to the discharge control system (Section 4), and finally designing a controller to generate commands for the ECH actuator system (Section 5).

2. Transition to real-time diagnostics

Previously, measured data were just recorded and analysed off-line with no time limitations for signal conditioning, filtering and computational algorithms. Information from other diagnostic systems were readily available and could easily be mapped to a common time base. The real-time constraint makes all those steps considerably harder.

An example is the data acquisition process. For off-line analysis it was most efficient to transfer the whole measurement data all-in-one from an external sampling device into the collecting computer's memory for processing and archiving. But for real-time control, data transfer has to be broken down into many small packets, which must be processed in-time, to feed the controller. Algorithms must also obey the causality constraint: only previously sampled data can be processed. Future samples, which could help in phase-preserving filtering, averaging or curve fitting interpolation, are not available.

On the other hand data conditioning and reduction is indispensable for further processing in order to reduce noise, provide meaningful values and comply with the communication network bandwidth and computing power available. MSE, magnetic, ECE and Mirnov diagnostic systems each acquire between 10 and 100 channels at sampling rates from 100 kHz to 2 MHz. For magnetic probe processing and equilibrium calculation we use a high-performance LabView installation [8]. The other diagnostic systems typically comprise several multi-core computers with real-time enabled Solaris or Linux operating system, which can be tightly coupled in network clusters. Their combined computing power is used to condition measurements with filtering, correlation and frequency analysis algorithms. These algorithms

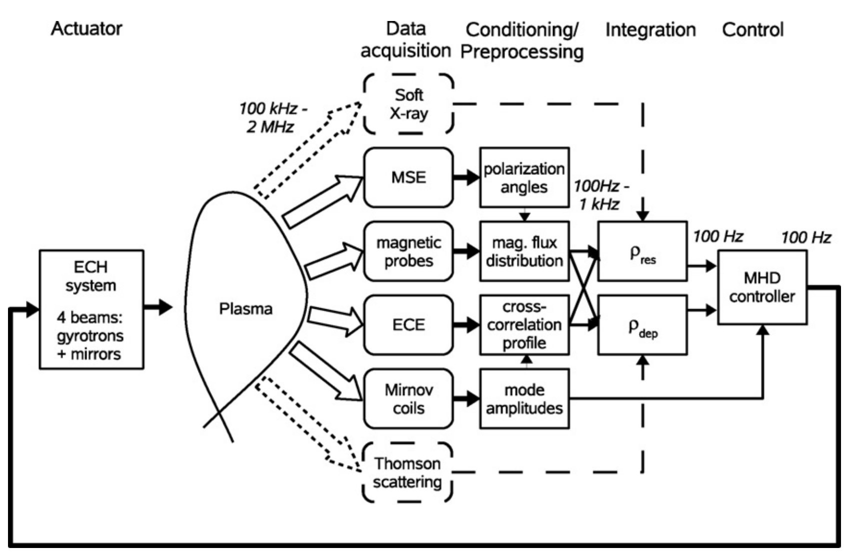

Fig. 2. Information flow for MHD control.