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FUSION-9608; No. of Pages 10
ARTICLE IN PRESS
Fusion Engineering and Design xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Fusion Engineering and Design
journal homepage: www.elsevier.com/locate/fusengdes

Diagnostics, data acquisition and control of the divertor test tokamak experiment

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ARTICLE INFO

Article history:
Received 11 August 2016
Received in revised form 24 May 2017
Accepted 24 May 2017
Available online xxx

Keywords:
Power exhaust
Plasma control
Diagnostics
Data acquisition

ABSTRACT

The system of diagnostics, data acquisition and control foreseen on the Divertor Test Tokamak experiment (DTT) is presented. Conceived in an integrated way, the control system meets the specifications of a fusion experiment devoted to the study of the power exhaust problem in view of DEMO. Diagnostics and feedback control are particularly functional to the need of maintaining the plasma close to equilibrium in situations prone to instabilities where the plasma wall interaction is optimized. Strongly oriented to the exploration of control methods suitable for DEMO, DTT will specifically experiment on physics and engineering model based control systems. Control and data flow schemes are inspired by those of ITER.

1. Introduction

The specific mission of the Divertor Test Tokamak [1] will be to explore viable solutions to the power exhaust issues in a fusion reactor in view of DEMO. The ultimate goal will be to qualify and control in various divertor configurations DEMO relevant heat flux densities to the wall in a way that preserves both the integrity of the plasma facing components and the quality of the plasma performance. In this paper, we describe the initial approach to the system of diagnostics, data acquisition and control infrastructure foreseen on DTT. Sensors, actuators, models and communication infrastructures are conceived in an integrated way in order to assure that the many interlaced functions of a complex fusion device, such as plasma control, machine-protection and safety, are fulfilled simultaneously. Whereby some redundancy is foreseen for model validation and reliable feedback control purposes it is important to bear in mind that one of the ultimate goals of DTT will be to explore DEMO relevant ways to control complex situations, which is with a minimal amount of direct measurements of the plasma parameters. This is to be accomplished by relying more and more on physics and engineering models driven controls [2].

The compatibility of the diagnostics with the present machine design has been verified particularly with regard to the geometry and paying attention to several other important specifications such as electromagnetic and radiation compatibility as well as maintenance issues. However a detailed and exhaustive verification of all these aspects is beyond the scope of this work.

In Chapter 2, the diagnostics system is described, mainly in terms of their functionalities and their main specifications. A set of fundamental diagnostic has been selected for both the develop-

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http://dx.doi.org/10.1016/j.fusengdes.2017.05.118
0920-3796/

Please cite this article in press as: R. Albanese, et al., Diagnostics, data acquisition and control of the divertor test tokamak experiment, Fusion Eng. Des. (2017), http://dx.doi.org/10.1016/j.fusengdes.2017.05.118

ment of the scientific basis of the experiment, the protection of the machine and the stable operation of the discharge under robust real time control. Chapter 3 describes in more details some of the principal situations where feedback control will be necessary for assuring long pulses, with particular reference to the specific mission of DTT. Data acquisition and control system that have been conceived according to modern schemes and tools are illustrated in Chapter 4 before some final remarks.

2. The DTT diagnostics

The main DTT diagnostics so far conceived for DTT are listed in Table 1, grouped according to the parameters to be measured and in Table 2 Table 2, organized in terms of their use for feedback control purposes. A brief description of the most relevant diagnostic systems is given. The specifications of the diagnostics are conceived in order to assure an adequate documentation of both core and edge plasmas. At the edge the diagnostics set up has to be able to qualify in the various divertor scenarios the space distribution of radiation, impurities and heat fluxes, identify the degree of plasma detachment, evaluate the level of impurity compression and plasma enrichment. In the core, particle and energy confinement, impurities and radiation have to be documented in all of the divertor solutions. Diagnostics sensor and actuators must allow control of the instabilities that deviate the system from a given equilibrium, such as vertical and radiation instabilities.

2.1. Magnetic diagnostic

The magnetic diagnostics are relevant to all of the basic functions (machine protection, plasma control, physics studies and performance evaluation). Sub-systems may be conceived on the basis of the different measurement techniques: Magnetic flux sensors; Magnetic field probes; Current transducers. Several plasma parameters can be deduced by a combination of different magnetic sub-systems, which can have therefore different roles in the architecture of the magnetic diagnostic (primary, backup, supplemental).

Exhaustive literature about generic magnetic diagnostics can be found in [3] but in general the DTT design inspires to the specific design of ITER [4]. A preliminary estimate of the total number of magnetic sensors for DTT is expected to be of the order of one thousand (in between the number of sensors presently exploited at JET [5] and those foreseen for ITER [6], that is approximately 500 and 1500 respectively). The design and manufacturing of magnetic sensors for DTT could also benefit from recent developments for ITER [7,8], such as loops and windings made of Mineral Insulated Cables (MIC) and magnetic field probes based on Low-Temperature co-fired Ceramics technology LTCC with pickup coils more compact and less sensitive to detrimental radiation induced effects.

2.2. Plasma equilibrium and shape

Besides the standard magnetic measurements (probes and saddle coils) several diagnostics will be integrated in equilibrium reconstruction models to evaluate equilibrium and plasma shape including the interferometer–polarimeter and CCD cameras. Here we describe in particular the interferometer polarimeter.

Interferometer-polarimeter

Two interferometer-polarimeter systems are foreseen: a few channels mid infrared (MIR) 10 μm: a 5 μm $CO2/CO$ *toroidal* system and a higher spatial resolution *poloidal* far infrared (FIR) one. The MIR vibration compensation scheme successful in both FTU and RFX-mod devices provides the reliable real time measurement of the chord averaged electron density [9]. The multi-chord FIR system measures the density and the plasma current profile (see

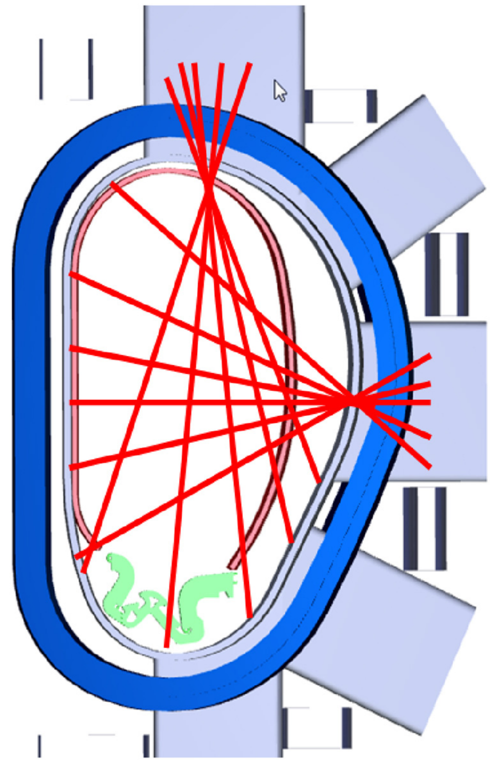

Fig. 1. interferometer-polarimeter viewing chords.

Fig. 1). In the low/medium density cases, the FIR system will provide a good magnetic field measurement and the MIR one will provide vibration compensation for density measurement, while in the high density case the short wavelength alone can provide magnetic field measurement from Faraday rotation and density measurement from the Cotton-Mouton effect. Optimal laser source solution for polarimetric measurements resilient to density gradients is the 100/50 μm one. Optically pumped CH3OH 118 μm gas lasers are commercially available (e.g. at RFX-mod). Gas laser sources in the 50 μm range are yet unavailable but the so called THz domain of QCL lasers is progressing. A conservative solution would be to use a 10.6 μm CO2 laser for the vibration compensation (Table 2).

2.3. Core kinetic profiles and fast particles

Several diagnostics are foreseen to document the kinetic content of the plasma core and the presence of non-Mawellian components in the particles energy distribution, the latter being particularly important for their possible impact on plasma wall interactions. Besides a Thomson Scattering system an ECE radiometer, charge exchange spectroscopy and a crystal spectrometer have been considered, while fast particles will be monitored by

ECE radiometer

Suitable not only for electron temperature measurements, but also for MHD qualification, kinetic profile analysis and pedestal characterization, preliminary evaluations of the ECE radiation as detected by an antenna located at R = 3. 25 m, z = 0.15 m and radial line of sight have been performed. Both 1st harmonics, O mode (O1: 130 < f < 250 GHz) and 2nd harmonics, X mode (X2: 260 <f < 380) spectral regions are detectable with adequate radial resolution, of 1 cm for the X2 and 2 cm for O1, respectively. The X2 has appropriate resolution for spatial detection of the MHD activity. O1 measurements in the HFS might be used for the characterization of the kinetic quantities in the pedestal.

Charge exchange spectroscopy

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