Fusion Engineering and Design 86 (2011) 548–551

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Overview on R&D and design activities for the ITER core charge exchange spectroscopy diagnostic system

W. Biel[a,*], T. Baross[g], P. Bourauel[a], D. Dunai[g], M. Durkut[c], G. Erdei[h], N. Hawkes[f], M.v. Hellermann[b], A. Hogenbirk[e], R. Jaspers[d], G. Kiss[a], F. Klinkhamer[c], J.F. Koning[b], V. Kotov[a], Y. Krasikov[a], A. Krimmer[a], O. Lischtschenko[b], A. Litnovsky[a], O. Marchuk[a], O. Neubauer[a], G. Offermanns[a], A. Panin[a], K. Patel[f], G. Pokol[h], M. Schrader[a], B. Snijders[c], V. Szabo[h], N. van der Valk[c], R. Voinchet[a], J. Wolters[a], S. Zoletnik[g]

[a] *Institut für Energieforschung – Plasmaphysik, Forschungszentrum Jülich Gmbh, Association EURATOM-FZJ, member of Trilateral Euregio Cluster, 52425 Jülich, Germany*
[b] *FOM-Institute for Plasma Physics Rijnhuizen, Association EURATOM-FOM, partner in the Trilateral Euregio Cluster and ITER-NL, P.O. Box 1207, 3430 BE Nieuwegein, The Netherlands*
[c] *TNO Science & Industry, Partner in ITER-NL, P.O. Box 155, 2600 AD Delft, The Netherlands*
[d] *Department of Applied Physics, Eindhoven University of Technology, The Netherlands*
[e] *Nuclear Research and Consultancy Group V.o.F., Petten, The Netherlands*
[f] *Association EURATOM/CCFE, OX14 3DB Abingdon, UK*
[g] *KFKI RMKI, EURATOM Association, PO Box 49, H-1521 Budapest, Hungary*
[h] *BME, EURATOM Association, PO Box 91, H-1521 Budapest, Hungary*

ARTICLE INFO

Article history:
Available online 29 April 2011

Keywords:
ITER
Diagnostic
Active spectroscopy
Upper port plug
Mechanical engineering
Optical design

ABSTRACT

The ITER core charge exchange recombination spectroscopy (core CXRS) diagnostic system is designed to provide experimental access to various measurement quantities in the ITER core plasma such as ion densities, temperatures and velocities. The implementation of the approved CXRS diagnostic principle on ITER faces significant challenges: First, a comparatively low CXRS signal intensity is expected, together with a high noise level due to bremsstrahlung, while the requested measurement accuracy and stability for the core CXRS system go far beyond the level commonly achieved in present-day fusion experiments. Second, the lifetime of the first mirror surface is limited due to either erosion by fast particle bombardment or deposition of impurities. Finally, the hostile technical environment on ITER imposes challenging boundary conditions for the diagnostic integration and operation, including high neutron loads, electromagnetic loads, seismic events and a limited access for maintenance. A brief overview on the R&D and design activities for the core CXRS system is presented here, while the details are described in parallel papers.

1. Introduction

The core CXRS (cCXRS) diagnostic is a powerful system being designed for the tokamak experiment ITER [1], aiming to provide experimental access to more than one quarter of the about 40 quantities listed in the ITER measurement requirements table [2]. It collects the light emitted from the interaction of the Diagnostic Neutral Beam (DNB) [3] with the core plasma and guides it via a mirror labyrinth through the Upper Port Plug #3 (UPP03) towards a fibre bundle, which then transmits the light to a set of spectrometers for spectral analysis. The requested measurement accuracy and stability for the CXRS system go far beyond the level commonly achieved in today's fusion experiments, while the hostile technical environment on ITER provides an extreme challenge for the design, integration and operation of the diagnostic system.

The most vulnerable component of the CXRS system is the first mirror, which is subject to erosion and deposition originating from neutral particle bombardment (hydrogen isotopes and plasma impurities). Additional challenges for the design activities are first the low expected CXRS signal intensity in the plasma centre caused by the attenuation of the neutral beam together with a high Bremsstrahlung continuum level, second the high neutron loads, generating thermal loads and hence stresses, third electro-magnetic loads generated from transient plasma events, furthermore seismic events and the limited access for system maintenance.

Within this paper, we provide a short overview on the status of ongoing research and design activities for the cCXRS system, while the details are described within several additional special contributions [4–15].

---

* Corresponding author. Tel.: +49 2461 61 5151.
E-mail address: w.biel@fz-juelich.de (W. Biel).

0920-3796/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.fusengdes.2011.02.086

2. CXRS diagnostic principle

Charge-exchange recombination spectroscopy is an active spectroscopic technique widely used in fusion research [16,17], where the photon-emitting excited states of a hydrogen-like impurity ion are populated by a collision transferring an electron from a hydrogen neutral particle to a fully stripped impurity ion A^{+q} in the plasma:

$$H + A^{+q} \rightarrow H^{+} + [A^{+(q-1)}]^{*} \quad (1)$$

A typical complete CXRS system consists of an energetic hydrogen neutral beam injected into the plasma and a spectroscopic observation system monitoring the emitted radiation from the beam-plasma interaction zone, where the geometric arrangement of beam direction and sightlines defines the achievable spatial resolution.

The CXRS principle is usually employed in the visible wavelength range, since here the population processes lead to high radiation intensities and the instrumental efforts needed to develop efficient observation systems are lower than in the ultraviolet or X-ray range. From the spectral analysis of the Doppler broadening and Doppler shift of the observed transitions, the local ion temperature and ion drift velocity can be derived, respectively. The measured intensity of spectral lines yields the absolute density of the fully stripped impurity species (for ITER the He ash density is most relevant), if accurate atomic data and an absolute intensity calibration of the observation system are available. The calibration of CXRS signals can also be accomplished by simultaneous measurement of the beam emission intensity (BES), since both depend on the local beam intensity [17,18].

Under conditions of the ITER reference discharge (inductive burn with density $n = 10^{20}\,\mathrm{m}^{-3}$), the broadband background radiation intensity from Bremsstrahlung, which is proportional to the mean ion charge Z_{eff}, will by far dominate over the low CXRS signals within the plasma centre. The quantity Z_{eff} can be derived from the background level of the CXRS spectra if the setup is absolutely calibrated and if additional light contributions from in-vessel light reflections are properly taken into account. In order to approach the measurement accuracy for cCXRS requested by the ITER measurement requirements [2], experiments and atomic data modeling are being performed to check and improve atomic data, see e.g. [19,20].

3. Status of the cCXRS reference design

On ITER a negative ion source-based diagnostic neutral beam (DNB) is foreseen in equatorial port #4 to inject a beam of hydrogen atoms with energy of 100 keV/amu, beam current 17–20 A and divergence ∼7 mrad into the plasma [3]. The ITER cCXRSdiagnostic comprises the in-vessel components, where a mirror labyrinth is located in UPP03, monitoring the beam-plasma interaction zone in the plasma core under oblique angle, and the ex-vessel components, where a fibre bundle transmits the light towards a set of spectrometers for spectral analysis, followed by data acquisition systems and analysis software. Within the past years, the so-called reference design for cCXRS was developed in some detail [11,21,22], which will be presented in the following sections (see Fig. 1). Since the detailed analysis reveals severe limitations for the performance and lifetime of this reference design [11,13], alternative new concepts are currently being developed [7,13,15] and they are briefly summarized here.

3.1. Mechanical engineering

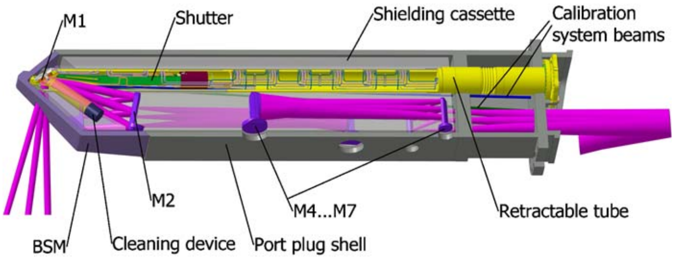

Fig. 1. Upper Port Plug #03 and cCXRS observation system with mirrors M1 . . . M7, selected optical paths and port plug components (cCXRS reference design).

The main components of the reference design for the CXRS port plug UP03 are the main shell, the shielding cassette, the retractable tube, a set of optical mirrors, a shutter, a calibration system and a cleaning system, which may serve to remove deposits from the first mirror by physical sputtering (see Fig. 1). The function of the main shell is to support the shielding cassette and the blanket shield module (BSM), and to provide the tritium confinement and vacuum boundary between the vacuum vessel primary vacuum and air. The cCXRS reference design includes a 3-point BSM attachment to the main shell, capable to react to electromagnetic loads caused by eddy- and halo currents with a good design margin. The main shell is connected to the vacuum vessel port by the plug flange.

The cassette provides the neutron shielding, supports the retractable tube and acts as an optical workbench for the secondary mirrors. It should serve for the full ITER lifetime with the possibility of unscheduled maintenance. The cassette is attached to the main shell by four keys at the shell nose (with sliding contact) and fixed to the main shell backside by a vacuum weld. Such support system excludes mutual dynamic oscillations of the shell and the cassette which can be caused by VDE events and seismic loads. According to this design, the cassette is to be inserted into the main shell from the plug backside.

The first mirror (M1) and the shutter for M1 protection are mounted onto a retractable tube (RT) in order to allow for maintenance access to these two vulnerable cCXRS components during each ITER shutdown phase (every 1–2 years). The maintenance implications related to the RT are studied in detail elsewhere [4,23]. The fast shutter can operate consistently with DNB pulses and uses elastic flexible elements for driving motions. The actuator is a frictionless linear drive of double action moving and fixing the arms with the help of pressurised He in the extreme positions. These extreme positions of the shutter arms are limited by bumpers attached to the RT and the arms with electrical insulation.

M1 is attached to the holder by a bolted frame via a mesh allowing for thermal expansion of M1 and working as a well-defined thermal conductor. The M1 holder provides mirror adjustment with a range of ±2 degree and precision of 1 mrad. The holder is cooled/baked by gaseous He to keep M1 within the working temperature interval of 300–400 °C during the plasma pulse and the dwell time for thermal conditioning. The material of M1 is single-crystalline molybdenum (ScMo), which is known to be quite stable against possible erosion due to sputtering [24].

A concept for a calibration system has been integrated into the cCXRS design, which consists of a diffuser mounted onto the backside of the shutter blades that is illuminated by a tungsten filament located outside the primary vacuum. The reflected light from the diffuser uses the same optical path as the cCXRS light. An additional separate radiometer channel is foreseen to monitor the spectral intensity of the diffuse back-reflected light emission of the tungsten lamp. Further research is needed to clarify the lifetime issues of the calibration system such as darkening due to contamination or radiation effects.

The most critical loads having an effect on the cCXRS in-vessel units are neutron heating and electromagnetic loads. Analysis of electromagnetic loads induced by vertical displacement events