EFDA–JET–CP(12)01/02

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** See annex of F. Romanelli et al, "Overview of JET Results",*
(23rd IAEA Fusion Energy Conference, Daejon, Republic of Korea (2010)).

Preprint of Paper to be submitted for publication in Proceedings of the
High Temperature Plasma Diagnostics (HTPD) 2012, Monterey, California, USA.
7th May 2012 - 10th May 2012

ABSTRACT

A 60kV neutral lithium diagnostic beam probes the edge plasma of JET for the measurement of electron density profiles. This paper describes recent enhancements of the diagnostic setup and new procedures for calibration and ion gun protection. The recently installed light splitting optics allows in parallel a spectrally resolved and a fast intensity measurement of the beam emission for fast density and fluctuation studies.

1. INTRODUCTION

An overview of the diagnostic setup at JET was presented at the last HTPD conference [1]. This paper describes recent developments: the installation of a new periscope head; improvements of the calibration methods; protection measures for operation with massive gas puffs for disruption mitigation; the installation of a light splitting optics sharing the light between a re-designed spectrometer and a fast 32-channel Avalanche Photo Diode (APD) camera. Results of the spectrometer based density diagnostic, a comparison with other density diagnostics and first results of the fast observation system are presented.

2. NEW PERISCOPE HEAD

In 2010 JET had shutdown for the installation of a Be/W ITER-like wall [2]. During this shutdown, the Li beam periscope head was replaced by a design which allows a replacement of the plasma facing mirror by remote handling (fig.1). After removing the old periscope head, we found damages of the old, gold coated, metal mirror, which explain the relatively low intensities which were observed in the 2009 experiments. For unknown reasons we found a restricted observation range of the periscope mirror. Hence we intend to install via remote handling a re-designed mirror holder, which supports the mirror with a tilt of 5 degrees to increase the observation angle.

3. BEAM INTO GAS INTENSITY CALIBRATION

The accuracy of the Li beam electron density profiles depends on an accurate, frequent relative intensity calibration. In the past, this measurement was performed infrequently in offline, beam- into-gas pulses where deuterium was introduced into the torus via the glow discharge gas introduction system. The total amount of injected gas was un-calibrated, hence the procedure was incompatible with fuel retention studies for the new wall. Therefore we developed an offline pulse scenario where the gas is introduced via a calibrated gas introduction module – this procedure is usually used for series of offline pulses, which can be performed every 5 minutes, e.g. for alignment optimisation. Furthermore, we perform an intensity calibration after each pulse by injecting the beam into a gas target which is created by the out-gassing wall. For this purpose, the beam control software was amended to allow two beam-extraction periods for a measurement during the pulse and after pulse termination. An intensity calibration is now available after almost every pulse hence we increased the accuracy of the density measurement.

4. SPECTRAL CALIBRATION

The spectral calibration of the observation system is based on calibration measurements with neon and xenon spectral lamps (671.7nm and 672.8nm). The lamps illuminate spare fibres in the optical enclosure in the diagnostic hall. The light is transferred towards the periscope mirror in the torus hall and back-reflected into fibres which are connected to the spectrometer in the diagnostic hall. The stability of this calibration is measured by monitoring impurity lines during the break down of each discharge.

5. MASSIVE GAS INJECTION FOR DISRUPTION MITIGATION

For the protection of the metal wall at high plasma currents, it became mandatory to mitigate plasma disruptions by massive gas injection[3]. A real time protection network checks several diagnostics for the development of a disruption and triggers, upon detection, a disruption mitigation valve (DMV). During the gas puff the torus pressure rises above 0.01mbar. Operation of the Li ion source at these high pressures might result in uncontrolled arcs in the ion gun which could deteriorate the source conditioning and/or destroy the emitter coatings. To mitigate the impact of the DMV gas puffs, we installed a high voltage inhibt which turns off the power supplies as soon as a DMV gas puff is requested. Furthermore, a pressure monitor is installed to disable the Li beam power supplies at source pressures above 10^{-4}mbar. The later method is rather slow because of the time constant of the available pressure measurement (~100ms), the first method turns off the power supplies prior to the pressure rise in the source. The HV circuits are discharged via resistors, the ~6kV extraction voltage drops to zero within 20ms, the 60kV acceleration voltage takes seconds to decay. First experiments with DMV gas puffs and Li beam HV inhibit have not yet shown any negative impact on the ion gun.

6. UPGRADE OF THE BEAM EMISSION DETECTION SYSTEM

A spectrally resolved measurement of the Doppler shifted Li beam emission is required for the spatial calibration of the Li beam observation system at JET [1]. The spectrometer/CCD camera detection system restricts the temporal resolution to frame rates of ~10-20ms, which is not fast enough for the study of fast events like Edge Localised Modes (ELMs) or pellet fuelled discharges. Hence, we developed light splitting optics which shares the light between a fast APD camera and a double-entrance-slit transmission-grating spectrometer. Optical fibres (core diameter d = 1mm, NA = 0.22) transfer the light from the Li beam periscope at the tokomak to the diagnostic hall [1]. They are arranged in three vertical fibre arrays which form the entrance fibre stacks of the beam splitting optics (fig.2). A distance of 1.35mm between the fibre centres was chosen to reduce the cross-talk of the system. A lens doublet (f = 240mm, d = 130mm) creates parallel light, about 12% of the light is reflected at a right angle into the spectrometer branch, the remaining light passes through an interference filter (Andover, λ_0 = 672.3nm, $\Delta\lambda$ = 2.4nm, d = 115mm) and is imaged with a twin of the entrance lens on three fibre stacks. 32 short fibre links connect to the 8*4 APD detector matrix (Hamamatsu S8550).

The design of the spectrometer branch is optimised to avoid a loss of light at the entrance slit. For this purpose, the light splitting mirror is of rectangular shape (14mm width and 140mm height). Two cylindrical lenses of focal length 190mm and 24mm create image points of rectangular shape (width 0.15mmm and height 0.8mm). The light cone lies within the entrance cone of the spectrometer input lens (Canon 85mm F/1.2 lens). The dispersive element is a Kaiser optical systems HoloSpec high-resolution transmission grating/prism (grism) [1], a Nikon 50mm lens with F = 1.2 creates an image on a Princeton Instruments PhotonMax512 back-illuminated CCD camera. The filter ring of the Canon lens supports an interference filter (Andover, $\lambda_0 = 672.3$nm, $\Delta\lambda = 4.4$nm, d = 60mm) to avoid an overlap of the spectra for the different entrance slits. A set of mirrors is used to block the light from the central fibre array and reduce the distance of the image off-axis fibre stacks. Minor misalignments of the optical setup made it necessary that we use the system without an entrance slit. The performance of the setup met the required accuracy for the spectral and spatial calibration, we found a dispersion of ~0.04nm/pixel or ~2.5nm/mm. The AdimTech [4] APD camera electronics at JET has a reduced bandwidth of 250 kHz to improve the signal-to-noise ratio, the data acquisition resolution is 14bit. To reduce the amount of stored data, only a subset of the data is stored in full temporal resolution of 0.5 to 1MHz, whereas down-sampled data are stored for all channels for a fast density profile analysis at frequencies of typically 50Khz.

7. RESULTS OF THE SPECTROMETER MEASUREMENT

From summer 2011, a reciprocating Langmuir probe [5, 6] became again available. The operation of the probe is restricted in H-mode (high confinement plasmas) to avoid damage of the probe head e.g. during ELM activity. We compare in fig.3 a low confinement mode density profile from the probe with the results of the Li beam and high-resolution Thomson scattering diagnostic [7] (HRTS). The probe scan takes about 150ms hence all available Li beam and HRTS data are shown for a time interval of +/−75ms. The probe and Li beam measurements are located at the same poloidal position but at different toroidal positions: both diagnostics probe the plasma vertically from the top at a major radius of R = 3.25m, whereas the HRTS measures in almost radial direction close to the midplane. Of particular interest for the Li beam analysis is the temperature profile information from the probe: a temperature profile is required for the Li beam analysis code, and only the reciprocating probe can provide this information deep inside the scrape-off layer. In the absence of the probe data, a temperature constraint is estimated on basis of the HRTS data (solid black line in the bottom of fig.3). Note that the different temperature estimates have little impact on the Li beam electron density profiles. The HRTS data in fig.3 has been shifted by 13mm in radial direction prior to mapping on the Li beam co-ordinate, the probe data is un-shifted. These are typical inaccuracies of plasma boundary diagnostic alignments at JET, which can be explained by inaccuracies of the EFIT equilibrium and inaccuracies of the mechanical alignment.

8. FIRST RESULTS OF THE FAST APD CAMERA MEASUREMENT

First measurements from the fast APD camera had a relatively large noise level, we meanwhile replaced the detector and optimised the camera electronics to allow an improved signal to noise ratio. There was no opportunity yet for new plasma measurements with the improved detector, hence we display in here only examples for a density analysis in an H-mode plasma with an ELM crash (fig.4). The beam emission from the APD camera has been averaged to 1ms, the intensity is cross-calibrated with the spectrometer data. In the middle of fig.4 we see the time traces with a resolution of 1ms. The density data during the ELM is disturbed by the uncertainty of the level of background light. An accurate analysis during an ELM crash requires fast beam modulation, a fast high voltage switch for the beam deflection voltages is currently in preparation which will allow a beam modulation of ~10kHz.

ACKNOWLEDGEMENT

This work, supported by the European Communities under the contract of Association between EURATOM and CCFE, was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission. This work was also part-funded by the RCUK Energy Programme under grant EP/I501045. The hardware improvements were undertaken within the framework of the Lithium beam upgrade project. The presenting author (M.B) likes to express his gratitude to the project leader S. Zoletnik, his team and P Blanchard. Furthermore he acknowledges the discussions with E. Wolfrum and J. Schweinzer. We thank P. Heesterman, A. Horton and C. Hogben for the integration of the APD camera into the JET data acquisition environment, J. Harling, P. Card, and P. McCullen for developing the new offline calibration procedure and the DMV high voltage protection and G. Kaveney, D. Croft and N. Balshaw for engineering support.

REFERENCES

[1]. M. Brix et al., Review of Scientific Instruments **81**, 10D733 (2010).

[2]. G.F. Matthews et al., Physica Scripta **T145** (2011) 014001

[3]. M Lehnen et al., Nuclear Fusion **51** (2011) 123010.

[4]. D. Dunai, S. Zoletnik, J. Sakozi and A. R. Field, Review of Scientific Instruments **81**, 103503 (2010),

[5]. S.J. Davies, S.K. Erents, A. Loarte, H.Y. Guo, G.F. Matthews, K McCormick and R.D. Monk, Contribution Plasma Physics **36** (1996) 117-124

[6]. C. Silva, Plasma Physics annd Controlled Fusion, **51** (2009) 105001

[7]. R. Pasqualotto, P. Nielsen, C. Gowers, M. Beurskens, M. Kempenaars, T. Carlstrom, and D. Johnson, Review of Scientific Instruments **75** (2004) 3891

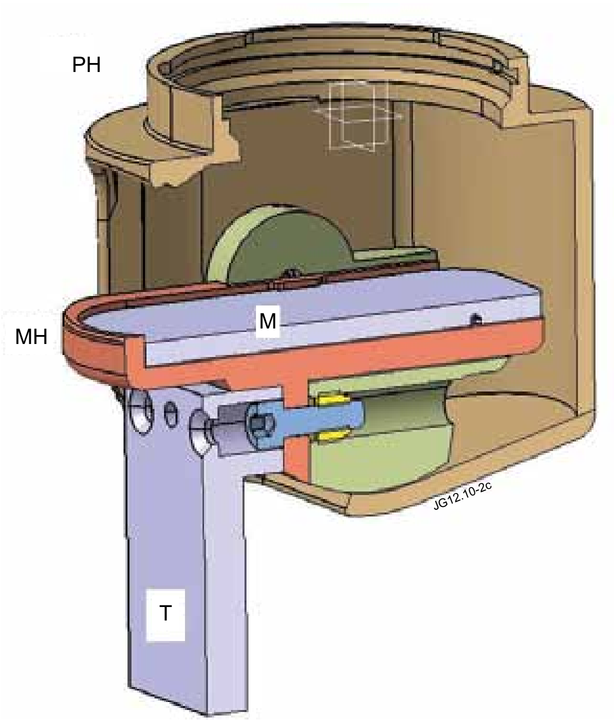

Figure 1: Periscope head PH, mirror M, mirror holder MH and remote handling tool T.

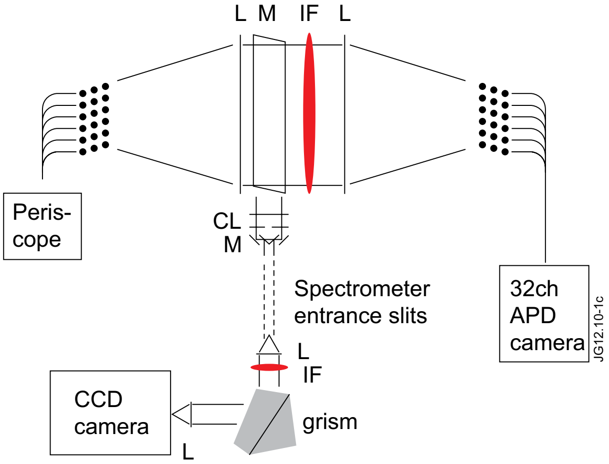

Figure 2: Beam splitting optics sharing light between an APD camera and CCD spectrometer. L: spherical lens, CL: cylindrical lens, IF interference filter, M: mirror, grism: high resolution transmission grating prism.

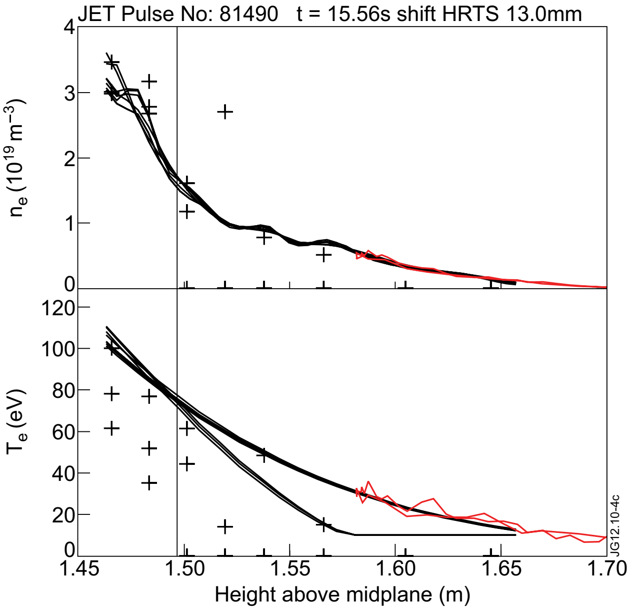

Figure 3: Comparison of Li beam profiles (black solid line) with reciprocating probe data (online: red, printed: grey) and HRTS measurements (+). The solid black curves in the temperature comparison are the estimated temperature profiles for the Li beam analysis code.

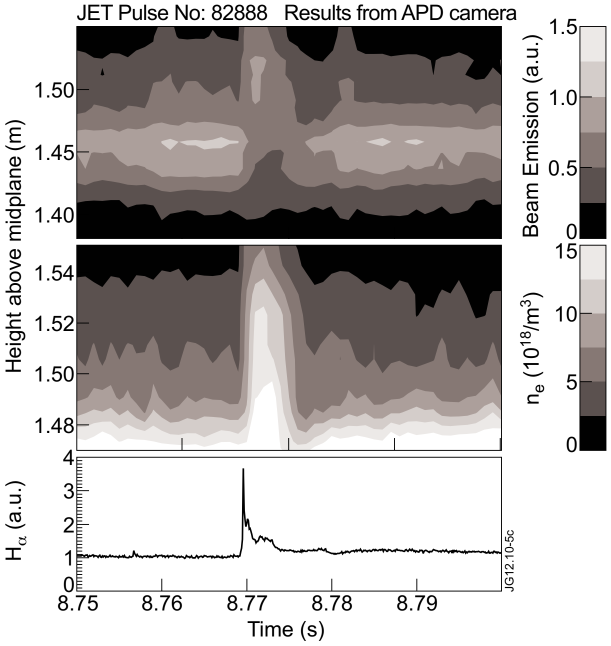

Figure 4: Fast density profiles from the APD camera measurement: top: beam emission profile, middle: density profile, bottom: Hα light with an ELM at t = 8.77s. The density during the ELM is invalid because of the rise of background light during the ELM.