EFDA–JET–CP(12)01/07

K.D. Lawson, R. Barnsley, C.F. Maggi, S. Tyrrell, M. Beldishevski,
J. Brzozowski, M. Buckley, G.Cass, T. Elevant, S.Griph, P. Heesterman,
C. Hogben, M. Jennison, M.F.Stamp, J. Williams, K-D. Zastrow
and JET EFDA contributors

Enhancements to the JET Poloidally Scanning VUV/Visible Spectrometers

Enhancements to the JET Poloidally Scanning VUV/Visible Spectrometers

K.D. Lawson[1], R. Barnsley[2], C.F. Maggi[3], S. Tyrrell[1], M. Beldishevski[1],
J. Brzozowski[4], M. Buckley[1], G.Cass[1], T. Elevant[4], S.Griph[1], P. Heesterman[1],
C. Hogben[1], M. Jennison[1], M.F.Stamp[1], J. Williams[1], K-D. Zastrow[1]
and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]EURATOM-CCFE Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK
[2]ITER Organization, Route de Vinon sur Verdon, 13115 Saint Paul lez Durance, France
[3]MPI für Plasmaphysik, EURATOM Association, D-85748, Garching, Germany
[4]EURATOM/VR Association, KTH Royal Institute of Technology, SE-100 44, Stockholm, Sweden
** 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

Enhancements to the JET poloidally scanning spectrometers are presented, which will aid the exploitation of the recently installed ITER-like wall in JET. They include the installation of visible filter/photomultiplier tube assemblies and spectrometers and the replacement of large rotating mirrors in the JET torus vacuum with small oscillating mirrors outside. The upgrade has resulted in a more robust and reliable diagnostic than before, which is described. The visible system has been absolutely calibrated using an in-vessel light source and drifts in the mirror angle reconstructed from quadrature encoder signals are attributed to a limitation of this technique, which requires a reference signal. The use of the small scanning mirrors necessitated the inclusion of focusing mirrors to maintain throughput into the VUV spectrometers. The mirror design has taken account of the extreme sensitivity of the focusing to the grazing angle of incidence, an aspect of importance in the design of grazing incidence focusing components on future machines, such as ITER.

1. INTRODUCTION

The poloidal distribution of impurity emission in locations neighbouring particle strike points is of particular value in the modelling of the impurity transport in the plasma edge. The lowest ionization stages, seen only in the visible spectral region, allow impurity influx measurements to be made, while higher ionization stages, seen mainly to shorter wavelengths, define impurity contents and, in some cases, allow parameters such as electron temperatures to be determined. All of these data provide valuable constraints on both edge and core impurity transport modelling. The measurements are of particular importance in gaining an understanding of the behaviour of the recently installed ITER-like wall in JET, with its Be and W plasma facing components. The emission profiles are measured with poloidally scanning spectrometers, known locally as KT1. There are 2 systems one situated on a top vertical port, the other on a horizontal port (figure 1).

2. OSCILLATING MIRRORS

A major enhancement has been to replace the large rotating mirrors, which were used to provide the poloidal scan, by small oscillating mirrors. The rotating mirrors were situated in the torus vacuum and, over the years, the feedthroughs necessary to drive the mirrors have resulted in a number of vacuum problems. Most recently, double bellows feedthroughs were installed in the mid-1990s, with an estimated lifetime of ~2 years of JET operations. Although their actual lifetime proved to be ~10 years, they have eventually failed. In the upgrade, all moving parts have been resited outside the torus vacuum, leading to a significant improvement in the integrity of the diagnostic.

Locating the mirrors on the diagnostic side of a torus valve increases their distance from the plasma, thereby reducing the extent of the poloidal scans. This reduction can be largely offset by the use of small, well-situated mirrors. The small mirrors nevertheless result in a loss of throughput into the VUV spectrometers, although this can be regained by employing a focusing mirror close to the VUV spectrometer entrance slits. The compact components used have two further advantages. The stepping motor used to drive the mirror in the vertical system, which has been found to stall in the high magnetic fields of the nearby Upper P2 and P3 poloidal coils, is small enough to be magnetically shielded by a soft iron cylinder. Also, their small inertia makes an oscillating rather than rotating movement possible, which reduces the dead time between scans. The oscillating mirrors are used by both the VUV and visible spectrometers and PMTs. Mirror speeds of 86.4 degrees/s are routinely used, giving a scan duration of ~125ms (vertical) and ~105ms (horizontal).

3. MIRROR ENCODERS AND LINES-OF-SIGHT

Two quadrature encoders are used to determine the angle of the line-of-sight on each system. The first is attached to the stepping motor used to drive the mirror and the second is internal to the vacuum being rigidly connected to the mirror. The speed of oscillation and the couplings (a stiff magnetic vacuum coupling, but more flexible couplings in the drive shaft) result in a nonuniform mirror movement and the internal encoder must be used to reconstruct the mirror angle. Even so, depending on the precise point at which the mirror turning point occurs relative to the quadrature signals, an extra count can be recorded leading to drifts in the reconstructed angle (figure 2). Such drifts appear to be a limitation of the technique, but can be corrected by a reference signal. An opto-electric switch is used to provide a reference signal in the present case and this will be repositioned so as to fall within the plasma scan during the next intervention.

The vertical system views the JET divertor and parts of the lower inner and outer main chamber walls (figure 1). During the upgrade, the lines-of-sight of the horizontal system were changed from a view of the lower inner wall to that around the upper strike points, this being the only spectrometer viewing this area of the JET torus. The poloidal angular ranges are 21.8 degrees (vertical), 18.2 and 16.4 degrees (VUV and visible horizontal). For the visible, the poloidal spatial resolution is ~1.5cm, with a toroidal view of 28 and 24cm for the vertical and horizontal systems, respectively. The poloidal resolution depends on the integration time and speed of the mirror rotation and these are limiting factors for the horizontal system VUV. The poloidal resolutions for the VUV are ~7cm (vertical) and ~15cm (horizontal).

4. VUV FOCUSING MIRRORS

A novel technique is deployed to regain the throughput of the VUV spectrometers, involving the use of grazing and neargrazing angle of incidence focusing mirrors [1], the mirrors fulfilling a similar function to the lens in the visible telescope.

Although grazing angles of incidence are required to maximize the VUV reflectivity of the focusing mirrors, such angles also result in the focusing being extremely sensitive to the angle of incidence (figure 3). This makes the alignment particularly critical. The horizontal spectrometer box is rigidly connected to the JET vessel port plate, the two moving together when the vessel temperature is changed. Consequently, a smaller grazing angle at the focussing mirror can be tolerated by this system, since extreme care can be taken over the alignment, which is then maintained. A larger grazing angle must be used for the vertical system, since the spectrometer box is decoupled from the vertical port plate. The limited opportunities for alignment when the JET vessel is at temperature

(~200°C) necessitates a more rapid alignment procedure, in which the angle of incidence at the focusing mirror need not be determined to the same high accuracy. The extreme sensitivity of the focussing on the angle of incidence must be considered in the design of grazing incidence instruments for future machines and indeed the ITER team is building on our experience.

5. SPECTROMETERS

The VUV spectrometers have provided data over a period of many years. They employ a 1m, 5° grazing incidence mount, with a 1200g/mm grating, blaze angle 300Å. Both vertical and horizontal systems have 2 detectors that each observe a single spectral line. The detectors consist of 2 back-to-back, chevron MicroChannel Plates (MCP) together with 16 multiwire anodes. The front surface of the first MCP is coated with 0.3 μm of CuI. In each detector 16 wires are used for 'slow' measurements allowing the spectral line profile to be observed. The spectral resolutions for the horizontal system are ~1.2 and 1.0Å and somewhat poorer ~6 and 4Å for the vertical system, in both cases these being for the short and long wavelength detectors, respectively. The output from the central 6 wires of the detectors is also clocked with a higher time resolution to give a 'fast' measurement. A 1 ms time resolution is normally used for the 'fast' channels of the vertical system and, since the intensities are lower, 10 ms for the horizontal. The wavelength range is ~200-1500Å, although with a minimum separation of the 2 lines observed due to the physical size of the detectors. The wavelengths are set remotely and can be changed between JET pulses.

The other major enhancement made in the present upgrade was to include a tritium compatible visible telescope in each system, a valve being incorporated into the beamline to separate the visible and VUV systems. The oscillating mirror has two sections, one coated with Pt for the VUV spectrometer and a second with Al for the visible systems. Light from the Al section is then directed into a visible telescope by an Al turning mirror, which is situated as close to the oscillating mirror as possible in order to maximize the visible intensity. Three quartz optical fibres are used to transmit light from the telescope to a spectrometer room remote from the JET torus hall. Two of these fibres are connected to interference filter/PhotoMultiplier Tube (PMT) assemblies, each assembly allowing 4 different spectral lines to be observed. The filters presently being used have a 10Å bandwidth and are for two lines each of D (D_α 6561Å and D_β 4860Å), Be (Be I 4673Å and Be II 5270Å), C (C II 6580Å and CIII 4650Å) and W (W I at 4009Å and 5225Å). The PMTs have a maximum time resolution of 200kHz, but are routinely used at 5kHz. The third fibre is connected to a Czerny-Turner spectrometer, which can record either spectra using a CCD detector or the time history of a single spectral line using a PMT.

Poloidal emission profiles have been recorded from the first pulse of the JET 2011 campaign, Pulse No: 80128. This is a 3.1T, 1.1MA, Ohmic, limiter discharge, the plasma lasting for 16s. Figure 4 shows intensity time histories recorded during one complete mirror oscillation with the horizontal system visible photomultiplier assemblies. Emission profiles are available as a function of time or as a function of poloidal angle. Figure 5 illustrates Be IV and D I time histories recorded with the vertical system VUV spectrometers for a 2T, 1.9MA, Ohmic, X-point discharge, pulse 80765.

In this case, two complete oscillations are shown, the D I emission peaks, which are close to the divertor strike points, being clearly seen on successive scans. Visible emission from a 2T, 2MA ELMy H-mode discharge with 10.5MW of neutral beam heating is shown in figure 6 as a function of poloidal angle. Again the observations are made using the vertical system and the emission associated with the strike points is most clearly seen in the Dβ trace. The weak W I signal includes some background emission.

The visible spectrometers have been absolutely calibrated using an in-vessel calibration light source positioned by remote handling arms [2]. The absolute sensitivity calibrations for the VUV spectrometers are obtained by cross-calibrations and branching ratio calibrations from other absolutely calibrated spectrometers.

ACKNOWLEDGEMENTS

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.

REFERENCES

[1]. I. H. Coffey and R. Barnsley, Review of Scientific Instruments, **75**, 3737 (2004)

[2]. T.M. Biewer, C. Belcher, I. Hassall, D.L. Hillis, G. Kaveney, M.F. Stamp, C. Stunell, K-D. Zastrow, (2012) this conference.

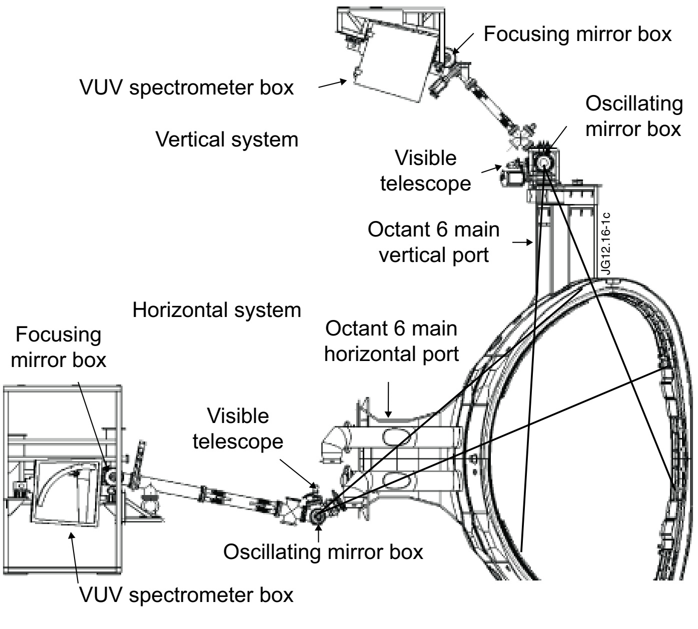

Figure 1: Diagram of the JET poloidally scanning spectrometers.

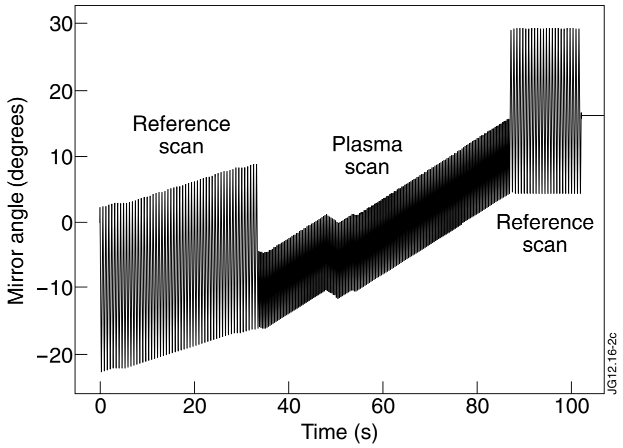

Figure 2: Drifts in the calculated mirror angle for JET Pulse No: 82674, showing pre- and post-plasma scans, which include a reference signal, and a narrower plasma scan.

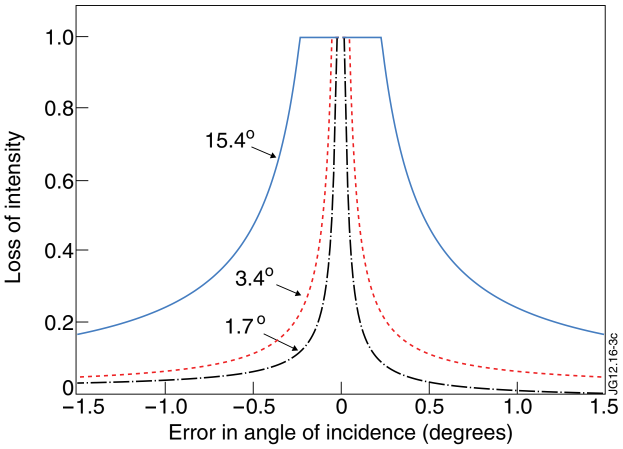

Figure 3. Sensitivity of the intensity on the error in the grazing angle of incidence at the focusing mirror. A minimum image height at the spectrometer entrance slit of 30μm is taken. A first design for the horizontal system had 1.7° grazing angle, the final design 3.4° and the vertical system 15.4°.

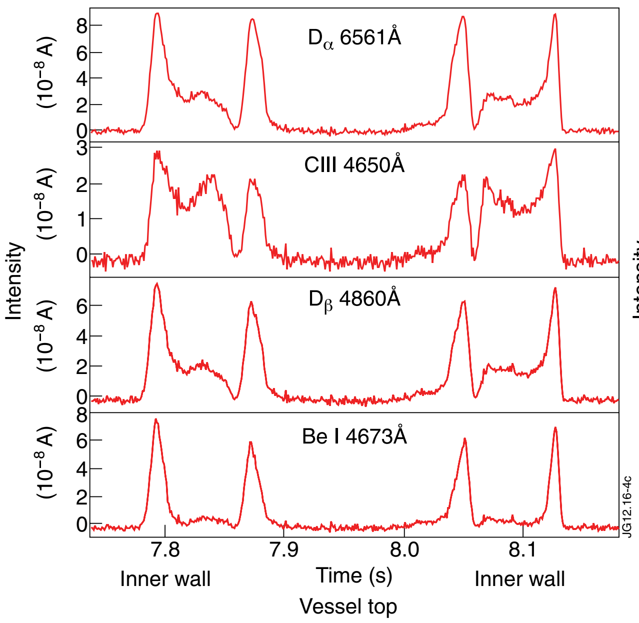

Figure 4: Horizontal system visible intensity time histories for Pulse No: 80128 - the first pulse of the 2011 JET campaign.

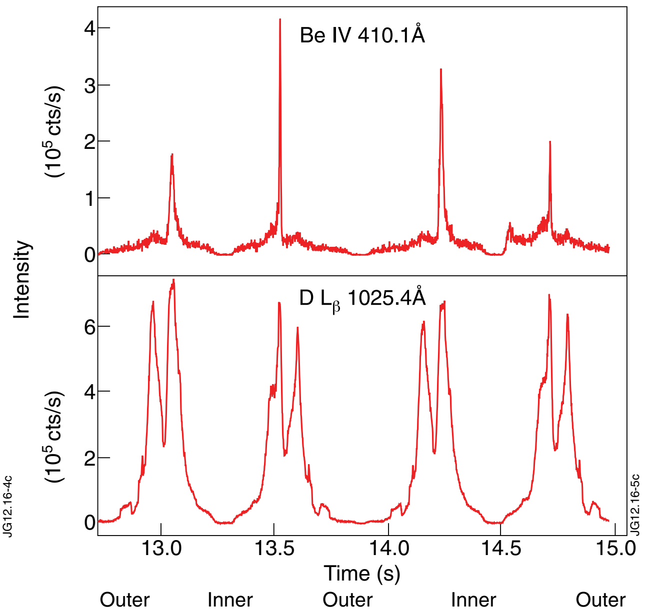

Figure 5: Vertical system VUV intensity time histories for JET Pulse No: 80765.

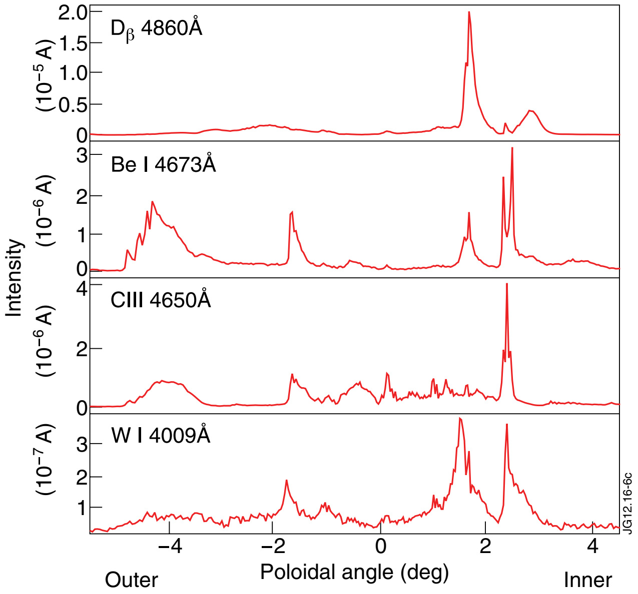

Figure 6: Vertical system visible intensities as a function of poloidal angle for JET Pulse No: 82200 (3.995-4.05s).