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ABSTRACT

LIDAR Thomson scattering has been used very successfully on the JET Tokamak to measure the evolution of profiles of electron temperature and density. Profiles with a spatial resolution of ~12 cm have been obtained throughout virtually all JET plasmas since the diagnostic installation was completed in mid-1987. The repetition rate of the system was enhanced from 1/2 to 4 Hz in 1994 by installing a higher repetition rate ruby laser. In this paper we describe a new LIDAR system, built around the old laser, which exploits the principle of probing a sight line at an angle to the flux surfaces to gain higher effective spatial resolution, 2-3 cm, in the edge and divertor plasma.

INTRODUCTION

By combining the time-of-flight or LIDAR principle with a Thomson backscattering diagnostic, spatial profiles of the electron temperature and density can be measured with a single set of detectors for all spatial points. The technique was realised for the first time on the JET tokamak and has been in routine operation since July 1987[1]. This approach considerably simplifies the collection optics required for measuring a spatial profile. Also, in comparison with the alternative more conventional ~90^0 Thomson scattering technique e.g. [2], alignment of the collection optics with respect to the input laser beam line is relatively easy to achieve and maintain. At JET this is accomplished remotely with the aid of a remotely controlled CCD camera. The ease of maintaining the alignment was an important factor in the choice of the LIDAR system for JET which is inaccessible for long periods. Currently, the Main JET LIDAR[3] system employs a ruby laser (1J pulse energy, 300ps pulse duration, 4Hz repetition rate) together with a 700MHhz bandwidth detection and digitization system to yield a spatial resolution of about 12cm. A large filter polychromator with 6 spectral channels covering the wavelength range of 400 - 800nm gives a dynamic range of the temperature measurements of 0.2-20keV. The stray light problem in backscattering geometry is overcome by spectral discrimination and effective gating (>10^8 rejection) of the MCP photomultipliers. A high rejection ruby notch filter in the spectral channel containing the laser wavelength allows calibration of the vignetting along the line of sight by means of Raman scattering, thus enabling the measurement of density profiles. The short integration time for an individual spatial point leads to a low level of plasma light on the detected signals with signal fluctuation levels dominated simply by the photo-electron count in the scattered signals themselves under most plasma conditions. The 12 cm spatial resolution of the original LIDAR system, though adequate for most core plasma diagnostic needs is insufficient to resolve some plasma edge phenomena. To try to improve this situation a new edge/Divertor LIDAR system has been constructed.

EDGE/DIVERTOR LIDAR DIAGNOSTIC

To achieve the improved spatial resolution, the backward scattered signal is collected along a chord that passes through the plasma just over the X-point, Fig.1. The angle of the laser beam with respect to the LCFS at the outboard side is ~ 30 degrees which together with the flux expansion gives a mid-plane equivalent spatial resolution ~4-5 times better than the resolution along the laser beam path.

The maximum equivalent mid-plane penetration of this path is between 5 and 10 cm depending on the position of the X-point and the alignment of the diagnostic. The effective F# of the collection system seen from the scattering volume is ~20. The subtended F# is ~14.

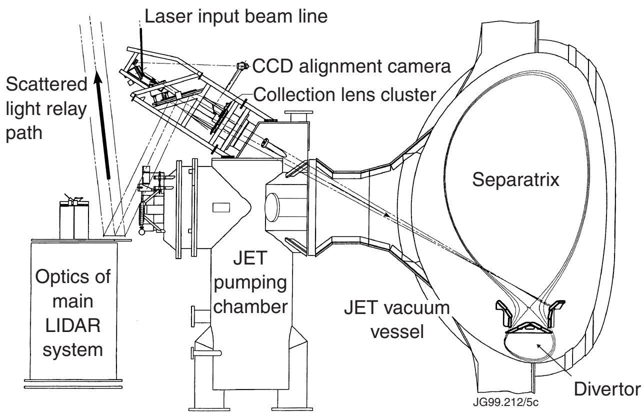

Fig.1: General layout of LIDAR Thomson scattering system used for edge measurements. The laser beam and the collected light are both passing through a penetration in the Torus Hall biological shield and a window cluster on top of the pumping box. Alignment is achieved by looking at the image on the divertor tile of a 633 nm alignment beam using a CCD camera inside the spectrometer

The system uses a 1 Hz repetition rate, 300 ps, 2 J ruby laser, fast gated MCP photomultipliers and a 1 GHz analog bandwidth, 4 channel HP-Infinium oscilloscope. The current set of ITT photomultipliers have a response time of 600 ps yielding an overall spatial resolution of ~12 cm along the laser path, resulting in an equivalent mid-plane resolution of 2-3 cm.

The scattered spectrum is measured by a four channel filter spectrometer, Fig.2. The optical path length is the same to all detectors. Cable lengths from the detectors to the oscilloscope are also kept the same, ensuring synchronization of the recorded signals of the four channels. A time marker is introduced optically from the laser on channel 1 to determine the absolute position of the scattered signal.

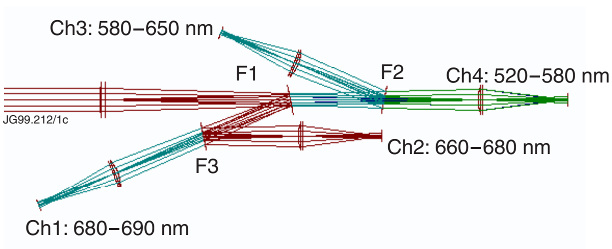

Fig.2: Four channel filter spectrometer. Input lens is at image of collection window. A lens in front of each detector images this lens onto each detector. Optical path lengths to detectors are the same. Shown are three filters at 12 degree incidence (F1 – F3) a fourth filter limits the channel nearest the laser line.

In a LIDAR Thomson scattering system the image is not fixed and the solid angle of collection varies with scattering position. In a complex system as on JET vignetting from apertures in the relay system can further complicate this. We have chosen to image the detector at the centre of the scattering path, making sure that this image is not vignetted by the relay optics. The solid angle of collection for all scattering volumes is then determined by this central image (40 mm diam.) and by the windows on the vacuum vessel. The laser beam size at the centre of scattering is ~5 mm. The étendue of the system resulting from this choice is sufficient to make the effect of vignetting insignificant in the outer half of the path.

THE SCATTERING VOLUME

The angle of the laser beam with respect to the LCFS at the outboard side is ~ 30 degrees which together with the flux expansion gives a mid-plane equivalent spatial resolution ~4 times better than the direct line of sight resolution. The flux expansion near the X-point is even greater but unfortunately we are not able to use the signal in this region due to the stray signal resulting from the leading edge of the laser pulse impinging on the divertor tiles. Better spatial resolution can be achieved by lowering the laser beam path nearer to the X-point. However this is achieved at the cost of smaller penetration into the plasma. Figure 3 shows the difference in spatial resolution resulting from lowering the scattering line by approximately 5 cm.

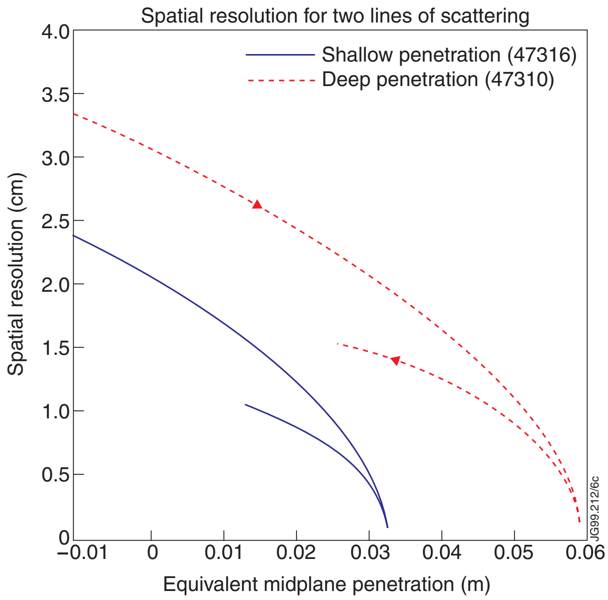

Fig.3: The spatial resolution vs. equivalent mid-plane position for a given discharge. The two curves demonstrate the effect of varying the path of the scattering system. The arrows show the direction of the laser beam as it enters from the outside.

RECENT RESULTS

Figure 4. shows a comparison of the electron temperature profile at the edge of an ELMy H-mode plasma measured by the new Edge/Divertor LIDAR system, the existing ECE Heterodyne diagnostic[4] and the main LIDAR system. The ECE and Edge LIDAR profiles have both been shifted by 5 cm outwards so that the dip in the ECE profile at 3.85 m lines up with the position of the LCFS derived from the EFIT equilibrium code. All three diagnostics have been independently calibrated and with the addition of this small shift the agreement between them is ~within experimental error. It is clear that spatial resolution of the main LIDAR system is not sufficient to resolve the detailed shape of the profile edge but within it’s measurement capability it agrees with the other two measurements. (The rise in the ECE signal outside the LCFS is produced by a calibration problem and is erroneous.)

Figure 5 shows a comparison of edge electron density profiles for the same plasma and time period as for fig.4, measured by the new Edge/Divertor LIDAR Thomson scattering system, the main LIDAR and the Li-beam diagnostic[5]. Again the profiles from the Li-beam and Edge LIDAR have been shifted outwards by the same 5 cm and once again this brings them into agreement with the position of the LCFS from EFIT. The steep edge density gradient clearly

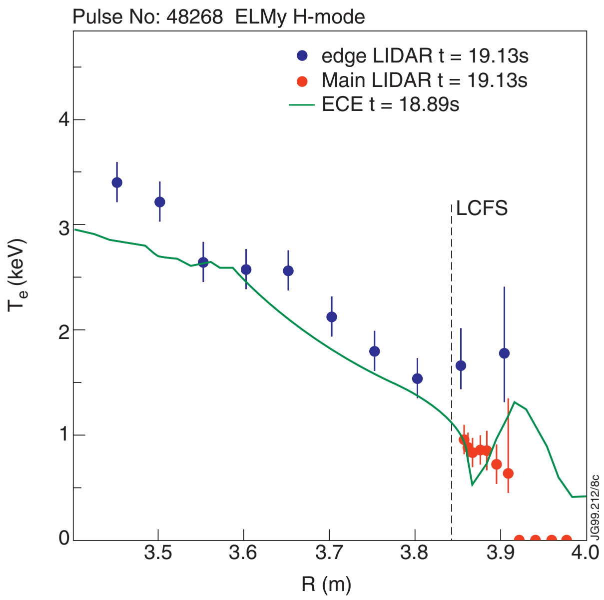

Fig.4: Comparison of Te from Edge LIDAR, Main LIDAR and Heterodyne ECE diagnostics showing agreement within experimental error between the 3 measurements.

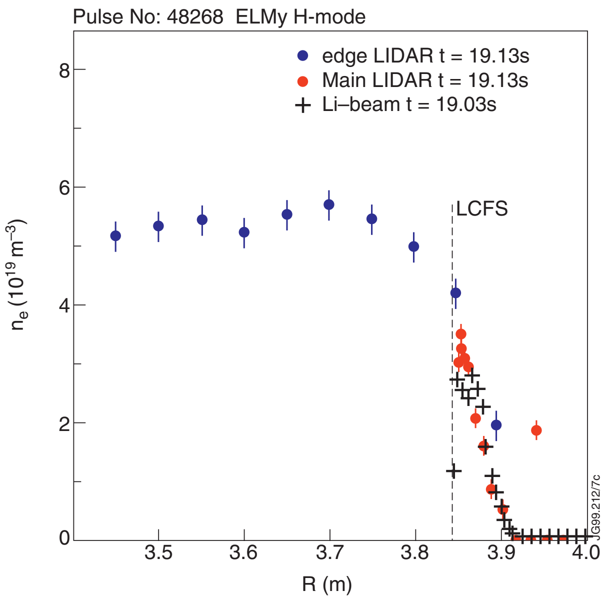

Fig.5: Comparison of ne from Edge LIDAR, Main LIDAR and Li-beam diagnostics again showing agreement within experimental error.

seen in the Li-beam and Edge LIDAR data is not resolved by the main LIDAR system but all three diagnostics agree within experimental error. For this plasma, all four diagnostics were able to function fully, but the Edge LIDAR system has proved to be a very useful tool in experiments where the shape of the plasma is strongly varied or where the conditions require relatively low toroidal field [6]. In the first case the Li-beam cannot reach the plasma and in the second the field was too low for the ECE instrument. Comparisons between plasmas of different shape relied on the Edge LIDAR system. The reason behind the need to shift the ECE and Edge LIDAR profiles is not at yet fully understood. However, certainly in the case of the edge LIDAR system, small changes in the position of the flux surfaces generated by the equilibrium code can have a significant effect on the effective profile position.

CONCLUSION

By aligning a LIDAR Thomson scattering system at an oblique angle to the poloidal flux surfaces we have shown that the basic 12 cm spatial resolution along the laser beam path can be converted into an effective resolution of 2-3 cm perpendicular to the flux surfaces. This allows the steep edge gradients found in the edge of ELMy H-mode plasmas to be much more clearly resolved. The technique may also be of value in a LIDAR system aligned at an oblique angle to the flux surfaces in the toroidal direction. In this case much higher spatial resolution around the internal transport barrier of optimised shear plasmas at JET could in principle be obtained, albeit with a significant loss of collection angle.

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