THOMSON SCATTERING IN ITER

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The ITER environment makes diagnostics a challenge and for several diagnostics makes it difficult or impossible to make measurements as we have become accustomed to on present devices. Thomson scattering seems to be one of the techniques that survive in these circumstances and up to four different systems are envisaged on ITER_FEAT. Thomson scattering is inherently insensitive to many variations of plasma parameters such as magnetic field. The difficulty in the case of ITER is more associated with the fact that a sufficient scattered light level is required resulting in large holes in the blanket witch potentially presents problems in neutron screening. The parameters that can be measured with Thomson scattering in ITER-FEAT are presented and details of the proposed solutions are discussed.

1 Introduction

ITER-FEAT requires an extensive set of plasma and first wall measurements. In general, the requirements on the measurements (parameter ranges, spatial resolutions and accuracy etc) will be the same or more demanding than those on contemporary machines. The harsh radiation environment means that diagnostic system selection and design has to take into account a range of effects and phenomena not previously encountered. This excludes the use of refractive optics at the front end even when using reflective optics we have to consider the effects of erosion and depositions on first mirrors. The diagnostic designs also have to satisfy the stringent engineering requirements for vacuum integrity, tritium containment, remote handling maintainability etc. Access will be restricted and must maintain neutron streaming below allowable limits. The value of some key plasma parameters will be significantly different from current machines (higher temperatures, longer pulse length (possibly steady state), larger physical size etc) which can significantly influence diagnostic performance.

In the design of diagnostics for ITER-FEAT Thomson scattering has become a key diagnostic technique. ITER-FEAT has been designed with large ports at the mid-plane, at the upper level and at the divertor level. The availability of large ports is of importance to optical systems like Thomson scattering that have to use reflective optics close to the plasma and which require large penetrations to get sufficient signal. Having ports at all three levels opens the options for making central measurements of electron temperature and density as well as higher

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resolution edge measurements and measurements in the divertor region. We shall describe in the following the four systems planned/considered for ITER-FEAT and their measuring capability, concentrating on the main LIDAR system.

2 The Core LIDAR System

2.1 General description

The core system is designed to provide an instrument capable of measuring the profiles of electron temperature and relative profiles of electron density in the main plasma (plasma core) in pulses for the pulse lengths of 400 s (reference) to 1000 s (extended) and up to 3000 s ('steady state').

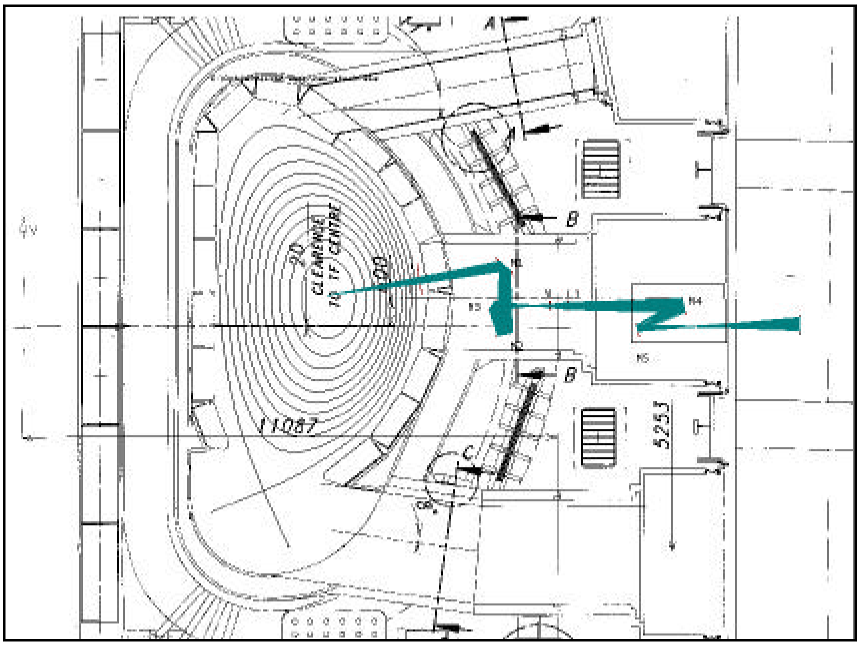

Figure 1: Layout of front-end of core LIDAR system. Three mirors M1-M3 form a neutron labyrint in the port plug. M4-M5 can be adjusted for alignment.

The system is an implementation of a LIDAR system, which relies on time of flight techniques of a short laser pulse for providing the required spatial resolution. A layout of the front end is shown in Figure 1. The optical elements inside the vacuum vessel are rigidly coupled to it and the movement relative to the building is taken up by a feedback controlled alignment system between the vacuum vessel and the cryostat. The transmitted and collected light are carried by an optical relay system to a dedicated area in the diagnostic hall

When the analysing instrument has to be far from the measuring volume some sort of optical relay system is employed. The relay system of a conventional scattering system would alternately image the scattering volume and alternately the collecting lens. In a LIDAR system there is no fixed scattering volume. The system at JET instead images the central scattering volume and the first collection mirror. Unfortunately the system also has other elements (the windows) that affect the variation of solid angle of collection as function of scattering position. The system is subject to variations with alignment and the variation of solid angle with position is measured by Raman scattering in air. In ITER-FEAT access will be much more restricted than on JET and routine measurement of the "vignetting curve" may be impossible. The optical components in the ITER-FEAT labyrinth has been designed to avoid these problems by relaying the input aperture (blanket penetration) and the collection mirror and making sure that no other elements in the optical train cause any further vignetting. Letting the laser beam use the same optics in the front-end guarantees alignment and the "vignetting curve" is easily calculated. Choosing to focus the laser at the plasma centre the variation of solid angle is a combination of two simple $1/R^2$ dependencies different from before and after the focal point. The size of the penetration the location and size of the first imaging mirror are directly related to the size of detector. The laser beam and the signal are separated outside the cryostat. The size of the laser beam is kept sufficiently large at the locations of vacuum windows to avoid laser damage threshold problems. A 3-times folded labyrinth in the poloidal plane is used to reduce the streaming neutron flux to an acceptable level, low enough to be able to use a fused silica primary vacuum window.

2.2 Mirrors and Mirror Mounts

The first mirror is flat, deflects the light by about 90° and has a major diameter of 0.4 m. The resulting hole in the blanket is 0.15 m. The first mirror is placed in a deep hole (1.75 m) to reduce the predicted erosion / deposition to an acceptable level. Calculation have been made of radiation and laser heating. None of the mirrors require active cooling. The mirrors are cooled by pulling the mirrors down to the cooled backing plate while compressing a metal or carbon felt mat for thermal contact. Since both the laser beam and the collected light passes the 5 mirrors inside the cryostat it is important to use a metal with high reflectivity in the spectral range 400 – 850 nm. Considering at the same the special environment this leaves few choices. Rhodium has been selected as the best material for the first mirror. However, we are still pushing to try to use silver for the subsequent mirrors with its much higher reflectivity.

2.3 Calibration

The biggest concern with the system is the effect of depositions on the first mirror. Various tests have demonstrated that coatings a fraction of a wavelength thick can significantly reduce the reflectivity. Spectral calibration of the system is therefore required on a routine basis. Relative spectral calibration can be made by using two different wavelength lasers. The ratio of the two spectra gives the electron temperature. Knowing the temperature the transmission at the different wavelengths can then be interpreted. The absolute calibration will subsequently have to be made by comparison to other density measurements, interferometry or reflectometry. In the end methods may have to found to clean the mirrors. Initial tests suggest that laser cleaning of metal mirrors is possible without damaging the mirror surface.

2.4 Performance

The requested performance for the system is a resolution of ~7 cm with a repetition rate of 100 Hz. We do not believe that this is practically possible. Instead we suggest to use two different lasers both operated at ~ 800nm (e.g.Ti:Sapphire). One high energy laser ~ 2 Joule (300 ps), 10 Hz for best resolution and a less stressed laser, ~.6 Joule (1 ns) @ 100 Hz. The latter laser would result in a resolution ~ 20 cm, adequate for most purposes.

3 The Edge System

3.1 General description

The Edge Thomson scattering system is a conventional scattering system. It is mounted in an upper port to take advantage of the flux expansion in this region. Figure 2 shows the layout of the front end. There are separate laser and collection lines within the diagnostic block. They are pre-aligned in the laboratory before the diagnostic block is inserted in the machine. In addition, beam steering external to the bioshield maintains the alignment between the laser and collection optics as the vessel moves.

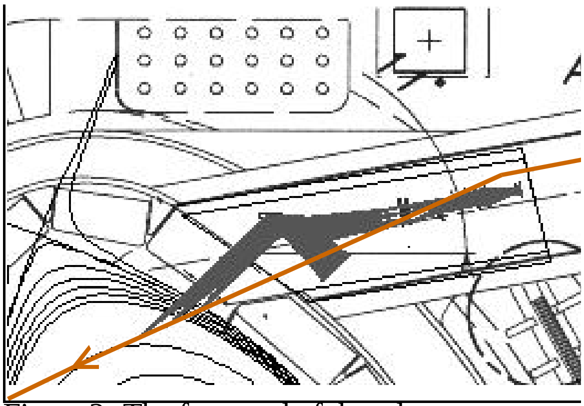

Figure 2: The front end of the edge system showing the depth of probing.

The laser beam is brought to the block using an evacuated transmission line. The collected light is taken out to the secondary barrier using heated fibre optic bundles to spectrometers in the diagnostic hall, although space is allowed for a return optical relay, if required.

In order to obtain the required spatial resolution the laser beam has to be pencil like over a long distance (<10 mm diameter over 60 cm). Since the scattering volumes are close to the port this means that the laser beam diameter will be relatively small at the front of the port plug (~ 20 mm). This size would not be a problem if use could be made of normal dielectric laser mirrors or quartz wedges. However, at this front location we have to use metal mirrors with much lower laser damage threshold. In order to be safe with respect to laser damage threshold on the first laser mirror this mirror has been placed as far back as possible for maximum beam expansion. This choice of laser line clearly restricts the possible depth of the measurement. The nominal flux plot shown gives a penetration to r/a = 0.9 equivalent midplane penetration.

3.2 Components

The port plug module contains a single aspherical imaging mirror, which images the scattering volumes onto a relay lens pair. Two plane mirrors bend the collected light path to provide neutron screening. The relay lenses follow, and are far enough back that the neutron flux does not cause darkening. The relay lenses image the imaging mirror onto the primary vacuum window. A composite lens after the window images the scattering volumes onto a fibre bundle.

3.3 Performance

The required midplane resolution of this system is 5 mm at a density of $5.x10^{19}$ m^{-3}. Taking advantage of the flux expansion this is reduced to a resolution of 1.5 cm. This sort of resolution can be achieved in present day systems using Nd:YAG lasers and filter spectrometers with APD detectors. The laser energy should be ~5 Joule (2 – 3 lasers). The imaging system has been designed to collect as much light as possible in the narrow space available. The astigmatism is not well corrected. However, the required resolution is achieved at the price of a somewhat higher background light level. With an effective F# ~ 10 this system is not significantly different from present systems.

4 The Divertor Systems

The divertor plays an important role in the ITER design. A key measurement is the position of the ionisation front to maintain partial detachment. However, there is also a desire to have a complete mapping of temperature and density in this area. Two Thomson scattering systems to meet these requirements as much as possible were designed by E.E.Mukhin et. al.[1] One system is a conventional system to measure all the way from the target plate to the X-point. The other system is a LIDAR system measuring across the plasma 0.5 m above the X-point.

The two systems are housed in each their selfcontained module in the bottom port of ITER-FEAT, Figure 3. The modules are fastened to the rails designed for the removal of the divertor casettes. This allows occasional servicing of the front end components.

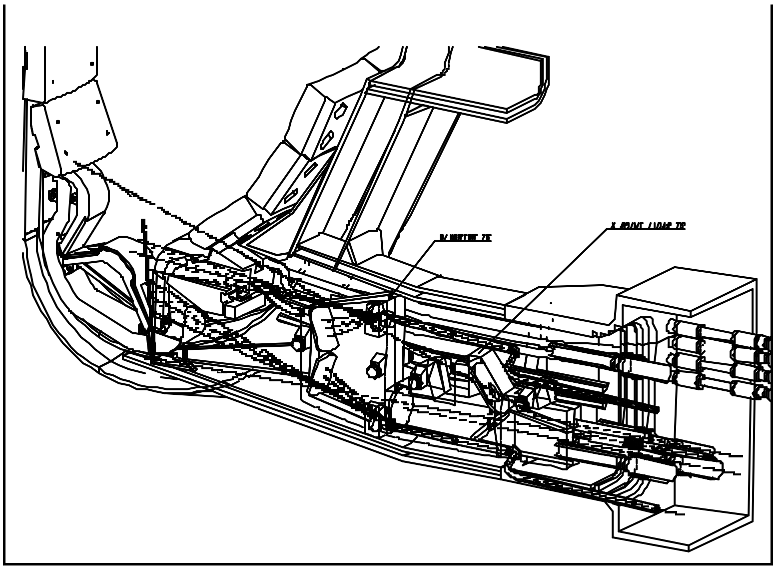

Figure 3: The Thomson scattering systems in the divertor port

4.1 The Divertor system

The laser for the divertor system is a 0.7 Joule Ti:Sapphire laser (λ=800nm). The collection system is F/15 allowing a spatial resolution of 5 cm at $n_e = 10^{19}$ m $^{-3}$. The detection system uses filter polychromators with APD detectors. The optics uses an aperture stop at the radius of curvature of the collection mirror to minimise astigmatism. The system will therefore in principle be capable of better spatial resolution at higher densities.

The laser enter at the bottom of the divertor casette. A diffraction grating (1000 lines/mm) directs the laser beam through a cutout at the cassette bottom towards the divertor. Tuning the laser wavelength to within 1nm allows precise angular alignment across the gap penetration. The grating anamorphic magnification reduces the beam cross section 4 times from (50 x 50mm) to (50 x 13mm). A thin focusing silica/diamond cylindrical lens housed in a dust-proof mount underneath the cassette provides additional collimating of the beam consistent with the designed gap penetrations and resolutions. To protect the grating from contamination by debris falling on it, a transparent shield will be installed over it. A gas jet system is proposed to remove falling debris.

4.2 The X-point LIDAR system

The X-point LIDAR system images the “detector” in the middle of the measuring region. Care is taken that no second vignetting takes place. The image is large enough that the system is insensitive to small variation in the pointing of the laser beam. To get better quantum efficiency it is proposed to use a 1 Joule frequency doubled ND:YLF laser (524 nm).

Frequency doubling immediately means that the pre-pulse lasing level is 10-12 of the fundamental. To reach the resolution of 5 cm streak camera is used as detector. A filter spectrometer with fibre coupling to the streak camera provides the measurement range of 10 eV-4 keV.

References

1 E.E.Mukhin, G.T.Razdobarin, V.V.Semenov, S.Yu.Tolstyakov, The interfaces for Thomson scattering diagnostics in the divertor and SOL near the X-point plasmas of ITER-FEAT, (Private communication)