POLARIMETRY FOR MEASURING THE CURRENT DENSITY IN ITER

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Abstract. A 10-chord poloidal polarimeter diagnostic is proposed to measure the current density profile in the ITER plasma. The optimum wavelength of such a polarimeter system is around 100 μm. At this wavelength the Faraday rotation angles are very large, whereas negative effects like refraction and electron cyclotron absorption are negligibly small. The Cotton-Mouton effect (change of ellipticity) has a significant effect on the polarization measurements at 100 μm and can be possibly used as a robust electron density measurement. The ten viewing chords of the ITER polarimeter cover almost the full poloidal cross section of the plasma in a fan-like arrangement. The probing beams enter the vacuum vessel through a penetration in the blanket modules at the low-field side. Retro-reflectors at the high field side mirror the laser beams back towards the penetrations at the low-field side.

1. Introduction

Many of the most promising results in magnetic confinement fusion were obtained in the so-called advanced scenarios, featuring a reversed magnetic shear. In most tokamaks the good results have been obtained during transient phases. To establish the good confinement conditions stationary an active feedback on the current density profile is desirable. It is for this reason that the ITER team has earmarked the current density profile as a potential machine control parameter. An extensive feasibility study by the Microwave Diagnostics Group of the European Home Team (made up by the authors of this paper) has led to the conclusion that a poloidal polarimeter system on ITER is, physically speaking, well feasible [1,2]. More recently the same team has concentrated its efforts on the conceptual technical design of the polarimeter system. This paper will briefly summarize the results of the feasibility calculation, followed by a more detailed presentation of the technical set-up.

2. Physical feasibility

Feasibility calculations have been done for a range of ITER equilibria and a set of artificially generated density profiles (ranging from peaked to flat) [1,2]. The line-averaged density was taken to be a factor of two above the Greenwald density for a plasma current of 21 MA.

Various viewing geometries, all in the poloidal plane, were considered, not at all constrained by the actual geometry of the ITER device.

The optimum wavelength for a poloidal polarimeter is around 100 μm. The Faraday rotation angles are very large at this wavelength (up to 80° for single passage through the plasma at the highest densities), and can be easily determined with high accuracy. Changes of ±0.05 in the central safety factor can be measured, even when the polarimeter has a modest sensitivity of 2.5°/m. The Cotton-Mouton effect (change of ellipticity) is relatively large at 100 μm and should be explicitly taken into account in the analysis of the polarimetry data. Although this is usually regarded as a disadvantage, it should not be the case in ITER. Namely, it is in principle possible to retrieve the line-averaged density from ellipsometric measurements. This kind of density measurements are not subject to fringe jumps, which often plague the standard interferometric measurements. A proof-of-principle of this technique has recently been given on the Wendelstein VII-AS stellarator [3].

Even under the most severe conditions (density a factor of two above Greenwald, peaked density profile, vertical viewing chord), refraction is negligibly small. The maximum displacement of the chord at 100 μm turned out to be only 6 mm over a 10 m long path. Ray-tracing for plasmas exhibiting MARFEs led to exactly the same conclusion. Absorption by very high harmonics of the electron cyclotron frequency is completely negligible under all conditions.

The above results were more or less the same for the various viewing geometries.

3. Technical set-up

The conceptual design of the polarimeter has concentrated around that geometry that is most straightforward from the technical point of view (see Fig. 1).

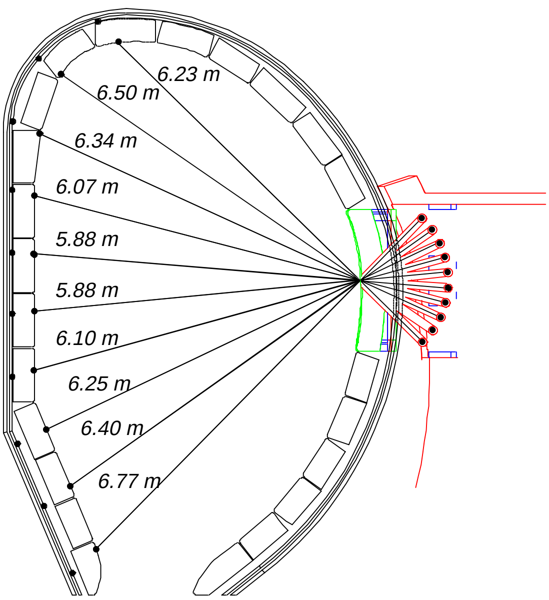

Figure 1. Geometrical lay-out of the poloidal polarimeter system for ITER. The distances between the retro reflectors at the high field side and the port penetration at the low field side are indicated.

The plasma is probed by a fan of ten chords that enter the plasma through a diagnostic plug at the low-field side (LFS). The ten chords cross at the plasma facing surface of the blanket. The chords lie in the poloidal plane and cover almost the full plasma cross section. Retro reflectors (RRs) at the high-field side (HFS) mirror the beams back along exactly the same chords. The first mirror is placed at a distance of 1.6 m behind the blanket surface. The second mirror is placed 0.55 m behind the first one, and is the only focussing element in the complete beam transfer system. The beam waist is located at the position of the retro-reflector.

The RRs consist of a single corner cube unit [4]. They are slightly indented with respect to the plasma facing surface of the blanket modules at the HFS, to minimize erosion and/or deposition. The RRs are either positioned in the gap between two neighbouring blanket modules or at the front surface of a single module. In both cases the modules should be slightly changed with respect to the standard blanket modules. Since the ITER Team is presently reconsidering the design of the modules, we did not yet put much effort in a detailed design of RR. Straightforward calculations have shown that it is possible to focus the beam to a ∅ 10 mm waist at the HFS. However, it is advantageous to have a somewhat larger waist at the HFS (15 – 17.5 mm), since this immediately has a positive effect on the required diameter of the port penetrations at the LFS. The size of the RRs should be at least a factor of 2.2 larger than the beam waist such that 99% of the incoming beam is reflected back. An optimum diameter of the RR would be about 50 mm; small misalignments and refraction would not severely effect the measurements.

With a beam waist of 17.5 mm at the RR, port penetrations of 90 - 100 mm diameter would in principle be sufficient to transmit more than 99% of the beam. However, to enable a certain degree of freedom in the alignment of the beams, the diameter of the penetrations has been fixed at 150 mm. Because the ten viewing chords cross at the LFS, the actual port penetration has an elongated cross section of 150 mm wide × 220 mm high.

Inside the port five of the beams are deflected by the first mirror in the co-current direction, whereas the other five are deflected in the counter-current direction (see Fig. 2). The second mirrors reflect the beams back into two planes (each with five beams), that are parallel to the probing plane. The first and second mirror are mounted in a special mirror assembly that can be easily removed from the diagnostic plug (in Fig. 2 the first and second mirror are positioned on a line perpendicular to the plane of the drawing). Special mechanical connections with pushing rods are used to steer the second, focussing mirror for alignment purposes. Quartz vacuum windows with a low birefringence are positioned at approximately 2 – 3 m behind the second mirror to form the primary vacuum boundary. The windows are slightly tilted to avoid any reflections of the incoming beam back into the laser.

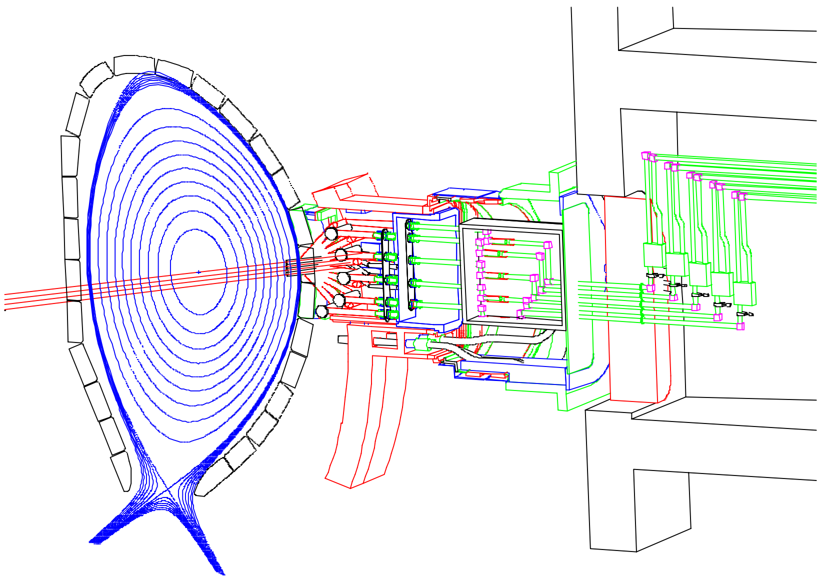

Figure 2. Schematic of the fully installed equatorial port of the polarimeter. The first and second mirror of each chord (black) are installed in the port plug. The interspace block (black box) contains the pre-aligned optics to compensate for any relative movements between the port plug and the bio-shield. The beam splitters/combiners (green boxes) are located in the access cell. From here waveguides run along the ceiling towards the local diagnostics area where laser(s) and detectors are placed. The four rays drawn in the plasma belong to another diagnostic.

Movements of the diagnostic plug with respect to the cryostat are accommodated by an interspace plug with four mirrors for each chord (see Fig. 2). Once aligned in a test-bed, this system maintains its alignment irrespective of any movements at either of its ends. The secondary vacuum boundary, a slightly tilted quartz window, is located directly behind the interspace plug. Straight waveguide sections bring the chords to the access cell outside the bio-shield. Here boxes with special optics are positioned to separate the two polarization components of the beam as well as to combine the incoming laser beams with the outgoing detection lines. Waveguides run from the access cell towards a local diagnostic area where the laser(s) and the detectors are placed. All waveguides a strongly oversized; the actual beam dimensions are determined purely by the focusing optics. The second waist of the chords is located in the boxes with beam splitters/combiners. This is done by either adapting the length of the beam paths in the interspace plug or by choosing proper focal lengths of the focussing mirrors for each chord.

The second mirror is the only focussing element in each viewing line. This is also the only element that is remotely steerable by means of pushing rods. Mirrors in the access cell, as well as in the local diagnostic area are remotely steerable. The first and second mirror, that are mounted in a special mirror assembly are pre-aligned in a test-bed. However, once they are positioned in the diagnostic plug they become inaccessible. From then onwards only the second mirror can be used for aligning the beam onto the RRs.

The main alignment problem is to position the beam waist exactly at the center of the RR. To cope with this, the second mirror will be equipped with a scanning mechanism, enabling to scan the beam over an area with a diameter of approximately 200 mm at the HFS (slightly different diameter for the various chords). That position where the reflected signal is maximum corresponds to the position of the RR. To enable the scanning of the beam over a limited surface at the HFS, the port penetrations through the blanket cannot be smaller than 150 mm.

Vibrations in the mirrors should be at such small a level that the beam is not deflected towards a position outside the retro reflector. For the first mirror this means that any angular vibrations should not exceed an angle of 0.1 degrees. To a certain extend, vibrations in the first and second mirror can be compensated by rigidly attaching both of them to a joint mechanical structure.

In the near future much attention will be devoted to a characterization of the retro reflectors, to a real-size mock up experiment to study especially the alignment issues and to simulations for a range of ITER equilibria to get a feeling for the precision of the polarimeter system.

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