*34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-1.159 (2007)*

FAST ION CTS DIAGNOSTIC FOR ITER - STATE OF DESIGN

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Introduction

Plasmas for thermonuclear fusion contain a highly non-thermal population of fast ions which may carry about one third of the plasma kinetic energy. Ions are accelerated to high energies by neutral beam injection or ion cyclotron resonance heating. They are also born in the deuterium-tritium fusion reaction which is the workhorse of α–particle heating for reactors which approach or reach the break-even condition. The dynamics of the fast ions plays an increasingly central role as fusion power plant conditions are approached: Fast ions must be confined in the plasma long enough to heat the bulk plasma. However, they also drive instabilities and turbulence and may leave the plasma before they have transferred their excess energy to the plasma. It is therefore essential to understand the dynamics of fast ions in fusion plasmas [1-2]. Collective Thomson scattering (CTS) offers the opportunity to diagnose confined fast ions resolved in space, velocity space, and in time, and the resolution and accuracy is adequate according to the ITER diagnostic requirements [1,3,4]. The CTS diagnostic has been previously successfully applied in the JET experiment [5] and in the TEXTOR experiment [6]. In CTS, one monitors a signal of millimetre waves resulting from scattering of a powerful beam of probe radiation on collective fluctuations in the electron distribution. The velocity distribution along a chosen direction can be inferred from the spectral content of the scattered radiation [7-8]. As the fast ion distribution may be highly anisotropic, the velocity distribution needs to be resolved in at least two directions: Perpendicular and parallel to the magnetic field. The spatial location of the measuring volume and the spatial resolution is given by the overlap of the probe beam and the receiver beam collecting the scattered signal.

The CTS diagnostic for ITER

A CTS system for ITER will utilize two 60 GHz gyrotrons with 1 MW power as sources of two probing beams. The system is capable of resolving the fast ion distribution in at least 16 velocity intervals with a spatial resolution of at least $1/10^{th}$ of the minor radius and a time resolution better than100 ms [3]. The gyrotron radiation enters the plasma on the low field side (LFS). For resolving velocities parallel to the magnetic field, the forward scattered CTS signal is captured on the high field side (HFS). For resolution of the perpendicular component, backscattered radiation is caught on the LFS. The CTS system for ITER differs from the previous successful CTS experiments on other machines [5,6] due to much larger heat and neutron fluxes in the ITER experiments, resulting in thermal strain on the equipment. Secondly, the CTS system for ITER has to be designed within the geometric constraints given by the machine. The scattered CTS-signal captured at the HFS in the vessel first needs to go from the plasma through the blanket of the inner wall of the vessel. Therefore, a slit with a dimension of 50 cm width and 3 cm height should be cut in the blanket. Figure 1 shows the part of the blanket, out of which the slit needs to be cut. To protect the other systems from the severe neutron and heat flux (e.g. the superconducting coils), the slits have to be as narrow as possible.

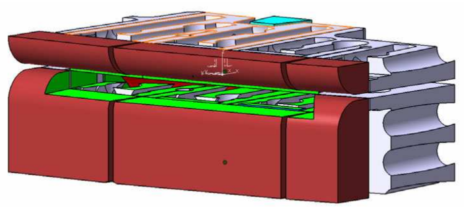

Fig. 1: Slit (green, 50 x 3 cm) in the blanket of the inner wall of ITER

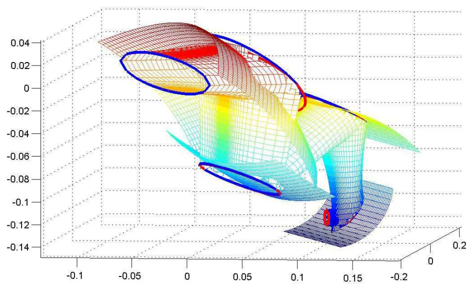

Fig. 2: Mirror shapes and transmission of the anisotropic Gaussian beam

A microwave beam passing through this aperture can be described as an anisotropic Gaussian beam for which the horizontal beam radius is 10 cm and the vertical beam radius is 1 cm. The aperture should be big enough to capture 1.6 times the Gaussian beam radius in order to catch 99.9% of the mm radiation and to avoid reflections. This will result in an aperture opening of 30 cm by 3 cm. Since a spatial profile of the CTS-signal is required, radiation from different angles in the horizontal plane shall be accepted. This requires an enlarged aperture in the horizontal direction with a width of approximately 50 cm.

The beam passing the aperture is anisotropic, but a receiver antenna which accepts isotropic radiation is preferred. Therefore, mirrors are required behind the blanket to reshape the anisotropic Gaussian beam to an isotropic Gaussian beam. The space for the mirrors behind the blanket is limited to 19 cm vertically, 30 cm horizontally, and 23 cm radially.

Calculation of Mirror Shapes

Keeping these boundary conditions in mind, the mirror shapes for a quasi optical transmission line were computed by calculating the propagation of an anisotropic Gaussian beam. The beam parameters at the slit in the blanket are given by the slit dimensions. The beam parameters required at the horn antenna are also given. The mirror shapes, required to transform the beam shape according to these boundary conditions, are calculated. Each mirror is a surface of a torus. The mirror surfaces and the beam shape are shown in figure 2. Figure 3 shows the beam radii in the two orthogonal directions of the anisotropic beam as it propagates through the transmission line. The green circles indicate positions of the mirrors; the blue circle indicates the position of the horn antenna. The data for the mirror surfaces were imported into CATIA, where the hardware design was made. Figure 4 shows the mirror assembly and figure 5 shows the mirror assembly integrated in the blanket. Figure 5 shows also the design which will be set up in the laboratory as a 1:1 mock-up in order to verify the calculation of the beam propagation (see figure 6).

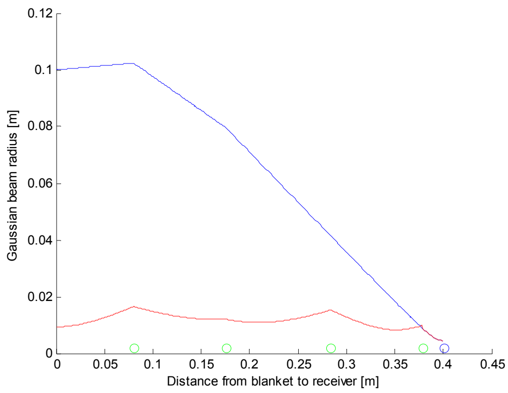

Fig. 3: Beam radius in two orthogonal directions while the beam propagates through the transmission line.

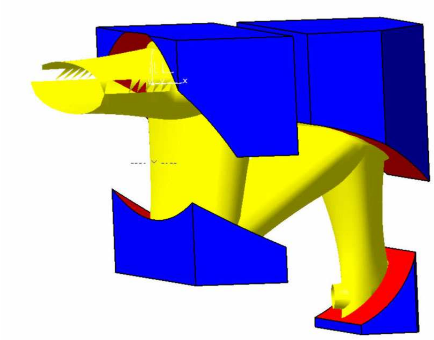

Fig. 4: Mirror assembly for the HFS CTS transmission line

Conclusions

The status and progress of the design of the collective Thomson scattering (CTS) diagnostic for ITER was discussed. The required shape of the mirrors in order to ensure an acceptable beam has been computed. The hardware was consequently designed and a 1:1 mock-up of the ITER CTS diagnostic was built to verify the computed propagation of the beam through the quasi-optics.

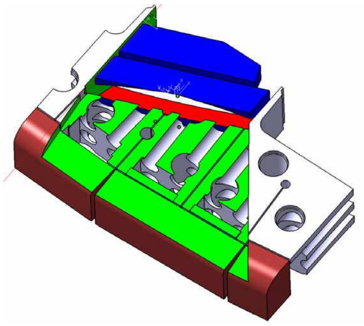

Fig. 5: Mirror assembly integrated in the blanket of the inner wall of ITER

Fig. 6 1:1 mock-up of the aperture in the vessel wall of ITER

Acknowledgements

This work, supported by the European Communities under the contract of Association between EURATOM/Risø, was carried out within the framework of the European Fusion Development Agreement [under EFDA Contracts 01.654 and 04-1213]. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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