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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 bulk 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. The resolution and accuracy meet 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 (given by the scattering geometry) 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 should optimally 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

The proposed 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 minimum 16 velocity intervals with a spatial resolution of approximately 1/10th of the minor radius and a time resolution better than 100 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), and for resolution of the perpendicular component, backscattered radiation is detected on the LFS.

The HFS antenna system

A mirror system for the HFS and its requirements including a 1:1 mock-up of the receiver was described and presented in [9]. It transforms the anisotropic Gaussian beam (size: 100mm x 10 mm) coming from the plasma to an isotropic Gaussian beam with a beam waist of 4.5 mm corresponding to a divergence angle of 20.3 degree, which can be accepted by a horn antenna. In order to verify the proper operation of the mirror system, the receiver horn antenna was fed by means of a Gunn diode and the beam shape was tracked backwards.

Based on [10] and the requirements of the mirror system, a corrugated horn antenna for a frequency of 60 GHz was designed and built. In order to verify whether the horn meets the requirements, a 60 GHz oscillator was mounted at the port of the horn and the device was used as a mm-wave source. The beam pattern in front of the horn opening was measured at various distances from the horn. Fig. 1 shows the beam radius versus the distance for two orthogonal directions. From these measurements, the divergence angle is obtained.

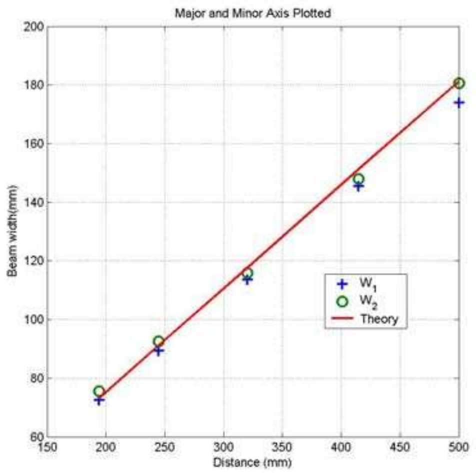

Fig. 1: Envelope of the beam leaving the horn. W1 and W2 should be identical, as the horn has a circular symmetry. The error is less than 3% between the measured beams in two orthogonal directions. The red line shows the expected divergence of the beam.

The beam was found to be slightly elliptical. The divergence angles for the major and minor axes were found to be 19 degree and 19.8 degree, respectively. The measured beam sizes in two orthogonal directions, W1 and W2, are in good agreement with the calculated beam sizes. In order to test the mirror assembly, the horn antenna is integrated into the mirror assembly (see Fig. 2). A detector, which is movable in the y-z-plane is used to characterize the beam pattern at various distances x from the mirror M1 (Fig. 2). The beam width in the horizontal and vertical directions at various distances from mirror M1 are shown in Fig. 3. The left graph in Fig. 3 shows the divergence of the beam at M1 in the vertical direction. The beam waist is calculated from the divergence angle and is found to be 9.49 mm. This is in good agreement with the calculated value of 10 mm. From the right graph in Fig. 3, only the horizontal width of approximately 100 mm and a converging beam can be seen.

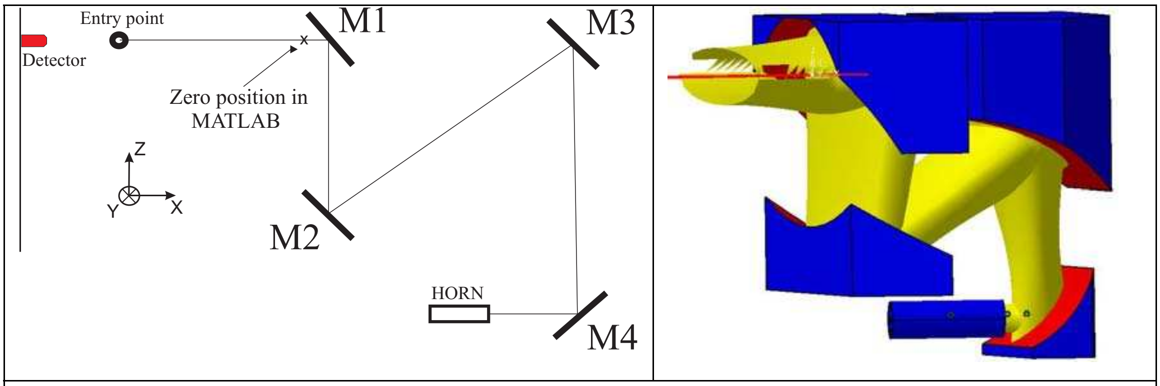

Fig. 2: Mirror assembly for the HFS CTS transmission line.

The beam could not be measured at distances larger than 0.35 meters from the mirror due to a low S/N ratio, which gives rise to a high uncertainty especially for the convergence angle. However, the characteristic is in agreement with the calculation. Microwave sources with higher power will be employed to overcome this problem. In the next step, the mirror assembly will be integrated into the blanket mock-up and the proper operation will be verified.

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 antenna system, consisting of mirror assembly and horn antenna has been verified experimentally with a 1:1 mock-up.

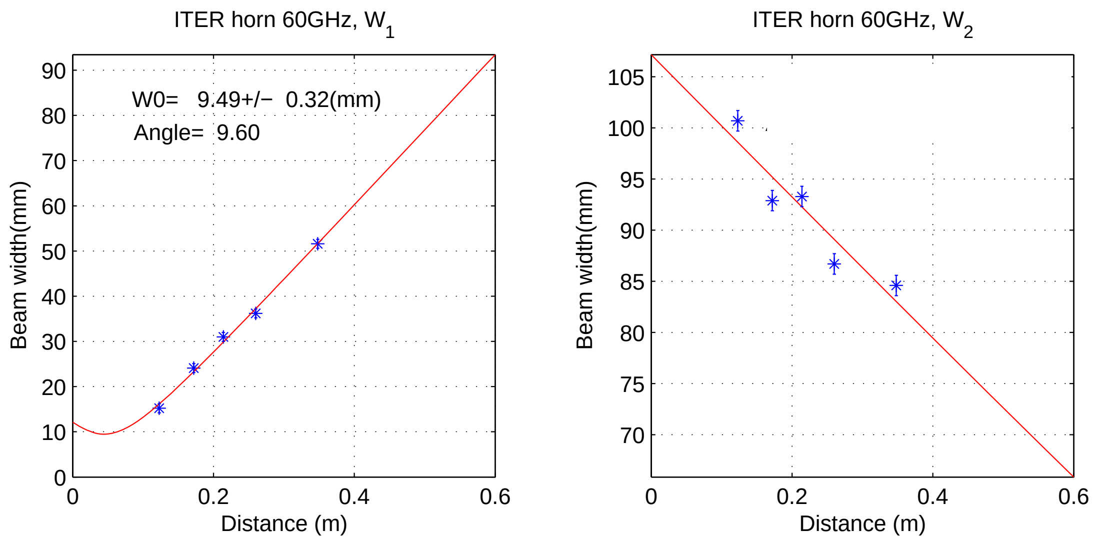

Fig. 3: Beam radius at various distances from mirror M1

Acknowledgements

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