35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.32D, P-5.077 (2008)

CTS diagnostic for anisotropic fast ion distributions on TEXTOR

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Introduction

The diagnosis of the fast ion populations in tokamak plasmas has been a topic of large interest for the fusion community throughout the years. Such diagnostics are needed both to verify the heating efficiency of the various fast ion heating methods, such as Ion Cyclotron Resonance Heating (ICRH) and Neutral Beam Injection (NBI), and to diagnose the alpha particles created in the D-T fusion reactions. Some of these fast ion sources are expected to be strongly anisotropic. The ICRH heated ions will have a large velocity component perpendicular to the magnetic field, the NBI injected fast ions will have a phase space distribution which is dependent on the injection geometry while the fusion born fast ions are expected to be close to isotropic.

Fast ions are known to interact with a number of plasma instabilities. This interaction is thought to be strongly dependent on the phase space distribution of the fast ions. Alfven waves are for example thought to interact with fast ions fulfilling the condition that the velocity component parallel to the magnetic field is equal to some fraction of the phase velocity of the wave [1] while the fishbone instability is thought to be resonant with the the toroidal precession frequency of the fast ions on the q=1 surface [2].

Collective Thomson scattering (CTS) has the capability of diagnosing the confined fast ion distribution in a well defined region of phase space, that is both physical space and velocity space [3, 4]. By scattering off fluctuations in the plasma using a high power microwave source, information about the fast ions may be obtained. However, in order to obtain a good quality overlap of the probe and receiver antenna pattern, good alignment techniques are important. In this proceeding a new alignment technique of the CTS system installed at the TEXTOR tokamak is presented. This technique has improved the knowledge of the obtained overlap significantly. Finally, the effect of the alignment is applied to a number of discharges where ICRH and NBI heated plasmas are diagnosed by CTS.

Collective Thomson scattering on TEXTOR

In CTS on TEXTOR a probe microwave beam of 110 GHz scatters off fluctuations in the plasma along the probe beam. The probe radiation is generated by a gyrotron with an output power of 300 kW for a time duration of 200 ms. A receiver system collects the scattered radiation from a localised region in space where the probe and receiver beam intersect. The wave vector of the resolved fluctuations in the plasma is given by $\mathbf{k}^\delta = \mathbf{k}^\mathrm{s} - \mathbf{k}^\mathrm{i}$ where $\mathbf{k}^\mathrm{i}$ and $\mathbf{k}^\mathrm{s}$ are the wave vectors of the incident and scattered radiation, respectively. The size and direction of $\mathbf{k}^\delta$ can be altered by changing the scattering geometry. The resolved frequency, ω^δ, is given by $\omega^\mathrm{s} - \omega^\mathrm{i}$. Again the superscripts s and i refer to incident and scattered radiation. As a rule of thumb, the scattering is collective when the scale length of the resolved fluctuation, $\frac{1}{\mathbf{k}^\delta}$, is larger than the Debye length. The frequency, ω^δ, of a particular wave vector component, $\mathbf{k}^\delta$, of the fluctuations driven by a particular ion is approximately given by $\omega^\delta = v_{ion} \cdot \mathbf{k}^\delta$, where v_{ion} is the velocity of the ion setting up the fluctuation. Here it is important to note that CTS can provide the 1D fast ion distribution function projected onto $\mathbf{k}^\delta$. In order to measure the fast ion dynamics with velocity components along the magnetic field (for instance NBI ions), a scattering geometry with $\angle(\mathbf{k}^\delta, \mathbf{B})$ close to zero is desirable whereas when the objective is to measure the dynamics of the fast ions with a velocity component perpendicular to the magnetic field (eg ICRH heated fast ions), a scattering geometry with $\angle(\mathbf{k}^\delta, \mathbf{B}) \sim 90\,^\circ$ should be obtained.

On TEXTOR, a close to backscattering CTS system is operational. Thus, when v_{perp} should be resolved, a radial injection of the probe and receiver beam is needed whereas a more toroidal direction of the beams is needed when the objective is to resolve v_{par}. Both the probe and receiver have motor controlled movable optics which facilitates geometry changes both in between shots but also during a discharge.

Microwave beam alignment

In order to obtain good beam overlap and to control both the spatial location of the overlap and the angle of the resolved fluctuations ($\angle(\mathbf{k}^\delta, \mathbf{B})$) to the magnetic field, a good alignment is needed. In order to get an easy reference system inside the tokamak a commercial 6 joint robotic arm was used. During an opening of TEXTOR this was installed temporarily and used to obtain a 3D coordinate system in TEXTOR. The robotic arm has a span of around 1 m and has a reproducibility which is better than 1 mm. The 110 GHz gyrotron was aligned by launching short bursts (a few ms) of microwave power onto fax paper with an echosorb backing for microwave absorption. The marks made by the gyrotron radiation on the echosorb were recorded by the robotic arm. The beam centre on the launcher mirror was recorded along with a number of points on the tokamak high field side for different gyrotron elevation and rotation angles. Previously, the CTS receiver beam pattern has been mapped out by a laser light technique [5]. This mapping was improved by measuring the microwave beam pattern inside the tokamak when a

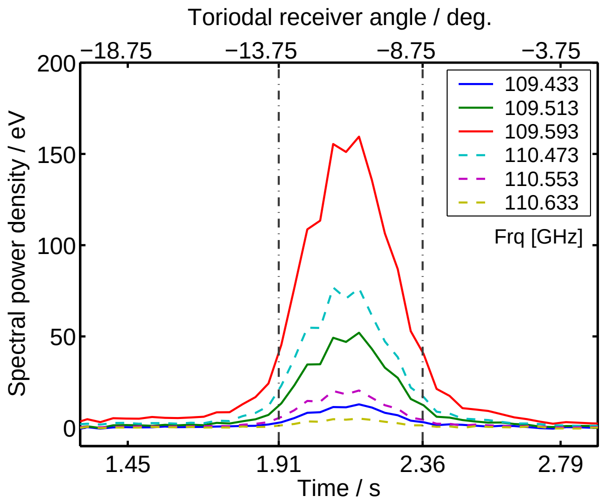

Figure 1: Overlap scan.

low power source was inserted in the CTS receiver and radiated out through the CTS transmission line. By installing a detector diode on the robotic arm, the arm can both be used to map out the beam pattern for a given mirror setting and to record the spatial position of the centre of the microwave beam. Once the robotic arm was removed from the TEXTOR vessel the recorded settings were reproduced at Risø and the absolute 3D position of the robot tool was measured with a precision greater than 1 mm. This eliminates any internal calibration errors in the 3D coordinate system of the robotic arm.

Results/discussion

When a new scattering geometry is found, the theoretical probe and receiver angles are calculated. The gyrotron launcher is set to the calculated values while the receiver mirror facing the plasma is programmed to sweep its angle by approximately 20 degrees around the calculated angle. When the overlap is strongest, the received signal is also strongest. This is done to verify that the received signal originates from scattered radiation and to ensure a good quality overlap. In figure 1, a discharge is shown where the receiver angle is changed in time. It is seen that the scattered radiation in the shown receiver channels peaks at the position of the overlap and decays away rapidly.

The alignment technique described above gave rise to a significant improvement of the alignment of both the 110 GHz gyrotron beam pattern and the CTS receiver beam pattern inside TEXTOR. The alignment was applied to previous experimentally obtained overlaps. Not only was the accuracy of the theoretical estimate of overlap improved, but the estimated location was also shifted by up to 5 cm.

When studying ICRH heated plasmas, a number of scattering geometries resolving fluctuations with $\angle(\mathbf{k}^{\delta},\mathbf{B}) \sim 90^{\circ}$ are needed while for NBI heated plasmas a number of geometries

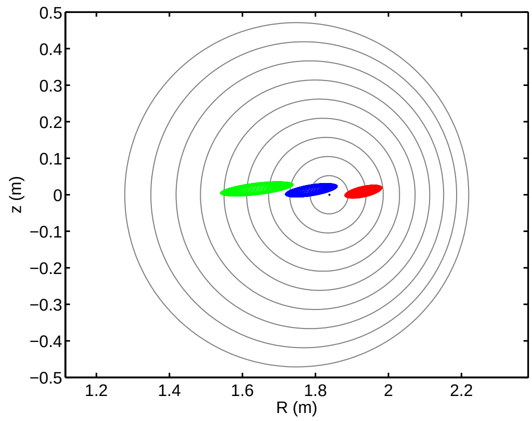

Figure 2: TEXTOR CTS overlaps for resolved angle of approximately 85 degrees

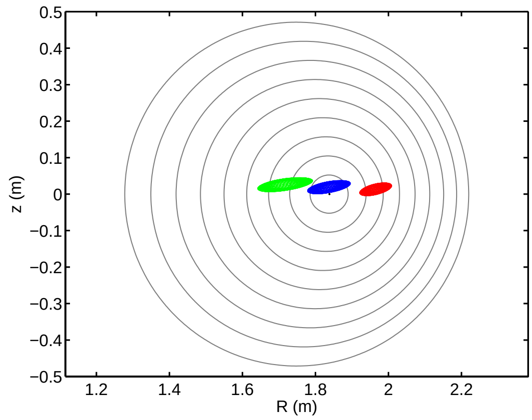

Figure 3: TEXTOR CTS overlaps for resolved angle of approximately 40 degrees

with smaller resolved angle are needed. In figure 2 three overlaps in TEXTOR at three different spatial locations are shown all with a resolved angle of approximately 85 degrees. Figure 3 shows three similar overlaps with $\angle(\mathbf{k}^{\delta},\mathbf{B}) \sim 40^{\circ}$. These six overlaps have been used to study both the dynamics of NBI heated plasmas and ICRH heated plasmas. The data are presently being analysed. The new alignment technique has improved the search for overlap in new scattering geometries at TEXTOR CTS significantly. This allows for detailed studies of the fast ion phase space distribution at TEXTOR where a number of fast ion sources are present.

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