Elevation angle alignment of quasi optical receiver mirrors of collective Thomson scattering diagnostic by sawtooth measurements

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Published in:
Review of Scientific Instruments

Link to article, DOI:
10.1063/1.4737387

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
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Citation: Rev. Sci. Instrum. 83, 10E337 (2012); doi: 10.1063/1.4737387
View online: http://dx.doi.org/10.1063/1.4737387
View Table of Contents: http://rsi.aip.org/resource/1/RSINAK/v83/i10
Published by the American Institute of Physics.

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Elevation angle alignment of quasi optical receiver mirrors of collective Thomson scattering diagnostic by sawtooth measurements


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(Submitted 8 May 2012; received 7 May 2012; accepted 4 June 2012; published online 31 July 2012)

Localized measurements of the fast ion velocity distribution function and the plasma composition measurements are of significant interest for the fusion community. Collective Thomson scattering (CTS) diagnostic allows such measurements with spatial and temporal resolution. Localized measurements require a good alignment of the optical path in the transmission line. Monitoring the alignment during the experiment greatly benefits the confidence in the CTS measurements. An in situ technique for the assessment of the elevation angle alignment of the receiver is developed. Using the CTS diagnostic on TEXTOR without a source of probing radiation in discharges with sawtooth oscillations, an elevation angle misalignment of 0.9° was found with an accuracy of 0.25°. © 2012 American Institute of Physics.

Fast ion physics is vital for fusion research since energetic particles influence the fusion yield, drive and suppress instabilities, and carry a significant part of the plasma current. Thus, resolving fast ion dynamics is important for the future success of ITER. The microwave-based collective Thomson scattering (CTS) diagnostic is able to perform spatially and temporally resolved measurements of the projection of the fast ion velocity distribution function along a direction determined by the scattering geometry. In some machines CTS was used for ion temperature measurements. Additionally, sensitivity of high resolution scattering spectra at certain geometries to the isotope content of the plasma was demonstrated and exploited. In order to interpret the experimental results correctly, the optical paths in the transmission lines for probe and receiver have to be well aligned. We focus here on the receiver beam transmission line. This technique is an added value since the alignment check of the whole transmission system can be only monitored during the vessel openings.

Therefore, in situ alignment checks during the experimental campaign greatly benefit the confidence in the measurements. The steerable mirror at the front-end portion of the receiver transmission line has two degrees of freedom: rotation about the vertical axis and about the horizontal axis. These are described by the elevation angle and the rotation angle, respectively (see Figure 1). The rotation and elevation angles determine the location of the scattering volume and the projection angle φ which in turn determines the velocity space interrogation region. Overlap sweeps, in which the probing beam is fixed and receiver beam is swept across it, are used to maximize the scattering from the overlap volume (where the scattering measurements take place) and verify the rotation angle alignment. Due to the relative placement of the probing and receiver mirrors (one above another in TEXTOR), the overlap sweep is not sensitive to the quality of the elevation angle alignment. The technique described in this article allows an elevation angle alignment check during a single plasma discharge.

During normal CTS operation, the magnetic field is chosen such that the resonance layers of electron cyclotron emission (ECE) in the CTS receiver frequency bandwidth are located outside the plasma. This is done in order to avoid absorption of the probing radiation and to facilitate an ECE background subtraction. For the vertical alignment check, contrarily to the normal CTS operation, the magnetic field strength is lowered to ensure that ECE in the receiver bandwidth originates from resonance layers intersecting the core of the plasma, as illustrated in Figure 2.

The CTS receiver is operated as an ECE radiometer, i.e., without a source of the probing radiation. In this regime the diagnostic is sensitive to the local changes in electron temperature and so can detect sawtooth oscillations.

The sawtooth instability is triggered by the m/n = 1/1 kink mode, therefore the instability occurs on the magnetic surface with the safety factor q = 1. The sawtooth crash is caused by the reconnection of the magnetic field lines and results in a sudden drop of electron temperature and density in the plasma core, followed by a slow increase of the pa-
parameters until the next sawtooth event is triggered. Outside the \( q = 1 \) surface, inverted sawteeth are observed. They are characterized by sudden increase of electron density and temperature, caused by ejection of hot electrons from inside the \( q = 1 \) surface. In TEXTOR, if no vertical shift is applied, the plasma is symmetric about the equatorial (\( z = 0 \)) plane, see Figure 2. Therefore, the \( q = 1 \) magnetic surface is also symmetric with respect to \( z = 0 \). The CTS receiver, being a sensitive radiometer, is capable of detection of the position where the resonance layer intersects the \( q = 1 \) magnetic surface. If the alignment is accurate, the ray-tracing technique which calculates the origin of the received radiation as a function of mirror position and plasma parameters should show that the position of the intersection points of the resonance layer with the \( q = 1 \) surface are symmetric with respect to the \( z = 0 \) plane. This is based on incoherent Thomson scattering measurements in many TEXTOR discharges. In order to perform the measurements, the receiver mirror has to undergo an elevation angle scan across the poloidal cross-section of the plasma. Setting the rotation angle of the mirror to zero, the influence of refraction is reduced, and so are the uncertain-

There are a number of reasons why the transition between normal and inverted sawtooth is not abrupt. The first reason is geometrical. On the magnetic surface where \( q = 1 \) exactly, electron temperature and density should not change at all. In the very proximity of the surface, changes are small. Second, the received beam is Gaussian and has a finite width.
This means that the received signal represents a weighted average of the emission over the beam width, so it is difficult to spot a precise location of the transition. An effect of a finite bandwidth of channels in the CTS receiver is negligible.

The location in the plasma, where the detected radiation originates from, is calculated using ray-tracing. The calculation is conducted independently for 33 CTS channels (the channels with large bandwidth, damaged channels, or channels with high attenuation are not considered). The centre of this transition time window between inverted and non-inverted sawteeth corresponds to the elevation antenna angle where the centre of the beam intersects the q = 1 surface. The duration of the period when no sawteeth are observed and the velocity of the scan set an error-bar on the vertical and angular position of the intersection location determined by ray-tracing. Figure 4 shows the calculated vertical positions of the intersection of the resonance layer for different channels as a function of the channel number (i.e., frequency), including the error-bars.

On TEXTOR, the magnetic axis is at the z = 0 position, hence the calculated values in Figure 4 should be centered around z = 0. However, the average calculated z-coordinate of all channel is ~27 mm. The standard deviation is \( \sigma_z = 7 \) mm, which is calculated by weighted averaging of the bisection points of all 33 channels:

\[
\bar{z}_c = \frac{\sum_{i=1}^{33} z_{c,i}/\sigma_i^2}{\sum_{i=1}^{33} 1/\sigma_i^2}
\]

\[
1/V = \sum_{i=1}^{33} 1/\sigma_i^2.
\]

Here \( \bar{z}_c \) is a weighted average of the z-coordinates of the bisection points of individual channels, \( z_{c,i} \) is a z-coordinate of the bisection point of channel \( i \), \( \sigma_i \) is a standard error of the z-coordinate of the bisection point of channel \( i \), \( V \) is a variance of the average simulated z-coordinate of the bisection point.

Figure 5 shows the vertical location of the bisection point calculated by the ray-tracing code as a function of an offset in the elevation angle.

Error-bars on the vertical position of the bisection point are calculated as errors of the vertical locations of the bisection point deduced from the measurements of individual channels, see Eq. (2). One can see that if no vertical offset is applied, the bisection point is not located at \( z = 0 \) m, as it should. However, when an offset of 0.9° is applied, the bisection point of the q = 1 plane is perfectly aligned with the equatorial plane of the tokamak. It implies that the front-end mirror has an elevation misalignment of 0.9° with an accuracy of 0.25°. We note that these results do not rely on information from other sources about the location of the q = 1 surface. Rather, they depend only on the symmetry of the q = 1 surface about the z = 0 plane.

The authors would like to express their gratitude to the TEXTOR team for its help in conducting the experiment and to Natalia Medissova for her help in improving the illustrations.