f004

Frequency shift of reflectometry signals due to rotation of density turbulence in W7-AS

B. Brañas*, M. Hirsch, J. Baldzuhn, T. Estrada*, T. Geist ,
H.J. Hartfuss, J. Sánchez*, V. Zhuravlev*
Max-Planck Institut für Plasmaphysik, EURATOM Ass., D-85748 Garching, FRG
**Asociación EURATOM-CIEMAT, 28040 Madrid, Spain*

Introduction

Reflectometry provides information about density fluctuations from a measurement of the phase changes of a mm-wave reflected at the cut-off layer in the plasma. Under turbulent plasma conditions an unidirectional drift of the measured phase is observed which cannot be explained by a realistic movement of the cut-off layer due to density changes. An understanding of this phase drift is essential for the interpretation of phase and amplitude of the reflected wave in terms of density turbulence. To clarify the situation two-dimensional simulations of the interaction between the mm-wave and the turbulent plasma have been performed[1,2]. They show that if parts of the wavefront reflected from different regions in the plasma interfere destructively at the receiving antenna sudden phase changes appear in combination with a drop in the signal amplitude. A preferential direction of this changes - i.e. a phase drift - results, if the density structures are rotating with the plasma. In addition some asymmetry between the reflecting structures and the wavefield must exist. The validity of such a model based on plasma rotation has been investigated experimentally with the reflectometer at W7-AS.

Experiments

The **reflectometer system**[3,4] at W7-AS combines heterodyne detection, a high dynamic range and bandwidth with operation at small wavelengths (X-mode propagation). The two poloidally separated antennas (θ=+6° and -6°) for launching and receiving the signal use Gaussian beams focused to a beam waist of 2cm in the plasma. The symmetry axis between the antennas is in the equatorial plane oriented towards the torus center at a toroidal position with elliptically elongated flux surfaces. The cut-off surfaces are almost perpendicular (87.4°) to the probing direction. An Amplitude Modulation system integrated into the reflectometer provides a time delay measurement which is used to obtain density profile information. All signals, carrier phase, time delay and signal amplitude, are sampled at 10 MHz. These characteristics make the system suitable for a detailed analysis of the reflectometer response to plasma density perturbations. From a previous study[1] instrumental reasons, e.g. insufficient sampling or an intermittent loss of signal power, can be excluded as the origin of the observed drift.

The observed phase drift strongly depends on plasma conditions. The most pronounced effect is its sudden disappearance in the H-mode[1]. Under typical L-mode conditions the magnitude of the phase drift shows a **characteristic radial profile**: it is positive for positions outside the separatrix and negative within the confinement region with a maximal red shift of a few 100 kHz. This red shift decreases towards the plasma center. If the drift is strong the phase spectrum has a 1/f dependence and the measured amplitude and phase signals show low coherence. In contrast, if the unidirectional phase drift is negligible in comparison with the symmetric phase fluctuations, the spectra differ from a 1/f dependence. In this case for frequencies $f > 50$ kHz amplitude and phase signals are coherent with a phase shift between them very close to $\pi/2$.

In order to test the **influence of the antenna geometry** on the observed drift transmitting and receiving antenna have been interchanged on a shot to shot basis using a variety of different plasma conditions (toroidal magnetic field of 1.25 / ±2.5 T, heating with 400/800 kW ECRH and 0.5 MW NBI, average density between 2 and 14 10^{19} m^{-3}, rotational transform 0.34 and 0.53): The observed phase drift does not change significantly when transmitting and receiving antenna are interchanged.

The **correlation between the phase drift and poloidal plasma rotation** has been investigated for two types of ECRH heated discharges which display different rotation profiles (Fig.1) : (1a) ECRH heating 400 kW off axis + 400 kW on axis and (1b) ECRH 400 kW off axis only. The poloidal rotation profile of the plasma is obtained as a sum of ExB and pressure driven rotation. The radial electric field is measured from the Doppler shift of impurity emission lines (B IV). As can be seen in Fig.1, for the two plasma conditions the radial profile of the phase drift qualitatively corresponds with the poloidal plasma rotation profile. For pure off-axis heating (Fig. 1b) the electron temperature and its gradient have very low values inside the heating location (r_{eff}~10 cm). Therefore the diamagnetic contribution to plasma rotation is very low at these positions, a feature that is also observed in the values of the phase drift.

An **inversion of plasma rotation** has been archieved by inverting the magnetic fields of the stellarator. All other plasma parameters are kept constant: Density and temperature profiles measured with Thomson scattering, Li-beam, reflectometry and ECE respectively show no variation as the magnetic field is reversed. Impurity rotation (BIV) changes sign confirming the inversion of the ExB velocity. An example of the observed phase drift is given in Fig. 2 ; For all probed radial positions the drift is inverted as the plasma rotation is reversed. In some discharges the absolute value of the drift measured for positive and negative magnetic fields nevertheless differs by up to a factor of 2.

A **detailed analysis of the phase changes** shows that the inversion of the drift is related to the shape of the measured phase fluctuations. Figs. 3 gives a detail of the phase and amplitude of a reflected signal for two corresponding discharges with positive and negative magnetic field. For example with positive B (Fig. 3b) during a fluctuation the measured phase increases faster than it decreases and the minima in the amplitude occur during the phase increase. This observation that the amplitude minima correlate with the bigger rates of phase change is consistent with the simulations. A coherency analysis shows that the coherence between phase and amplitude is high for frequencies 50 kHz < f < 2 MHz and the phase shift between both signals is $\pm\pi/2$ for positive and negative magnetic field respectively.

As during this period the phase does not always recover to its previous value, in the long term a drift in negative direction is obtained. This **intermittent behaviour** can be explained taking into account that the phase responds non linearly to changes in the local density gradient induced by the fluctuations. This local gradient is a function of the average one, the amplitude and the wavelength of the fluctuations. An intermittent phase drift appears if for certain time intervals, the turbulent structures are such that the microwaves reflected at them interfere destructively at the antenna. During the rest of the time the amplitudes of the density turbulence are lower or their wavelengths are larger therefore all power received at the antenna is reflected at a smoother surface i.e. at the same distance to the horn. Another explanation would be that the intermittence occurs due to small turbulence structures, that appear and disappear.

Discussion

The experimental results obtained with the reflectometer at W7-AS are compatible with an explanation of the observed phase drift based on density structures rotating with the plasma. As the direction of the drift can be inverted by inverting plasma rotation radially propagating density bursts can be excluded to be the main origin of the phase drift.

For the origin of the asymmetry in the reflected wavefield necessary to explain a net phase drift some experimental clues can be given : A vertical displacement of the plasma larger than 2-3 mm with respect to the antenna axis can be excluded from the lack of profile change as the magnetic field is reversed. Following the 2D WKB code calculations this small displacement can not produce the required asymmetry unless the turbulent structures have very high amplitude or very short poloidal wavelengths. The same holds for the small 2.6° misalignment of the horn axis from the normal to the cut-off surfaces. According the 2D simulations[2] the poloidal separation of emitting and receiving horns could introduce the required asymmetry. Nevertheless the experiments show that the phase drift does not change significantly as the horns are interchanged. Therefore the experimental results would be consistent with an explanation of the phase drift based mainly on an asymmetry in the turbulent structures themselves. As the observed phase drift direction is inverted when inverting the magnetic fields in this case the asymmetry must be independent on the rotation direction. In order to obtain more conclusive results 2D full-wave simulations are currently under way.

References

[1] B. Brañas, M. Hirsch, V. Zhuravlev, J. Sánchez, E. de la Luna, T. Estrada, T. Geist, H. J. Hartfuß, Proc. of the 22nd EPS Conference, Bournemouth, UK, 3-7 July 1995, Vol. 4, p 161.

[2] J. H. Irby, S. Horne, I. H. Hutchinson, P. C. Stek, Plasma Phys. Control. Fusion. 35, 601 (1993).

[3] H. J. Hartfuss, T. Estrada, M. Hirsch et al., Rev. Sci. Instrum 65(7), 2284 (1994).

[4] M. Hirsch, H.J. Hartfuß, T. Geist, E. de la Luna, Rev. Sci. Instrum. 67(5), p1807 (1996)

Fig.1

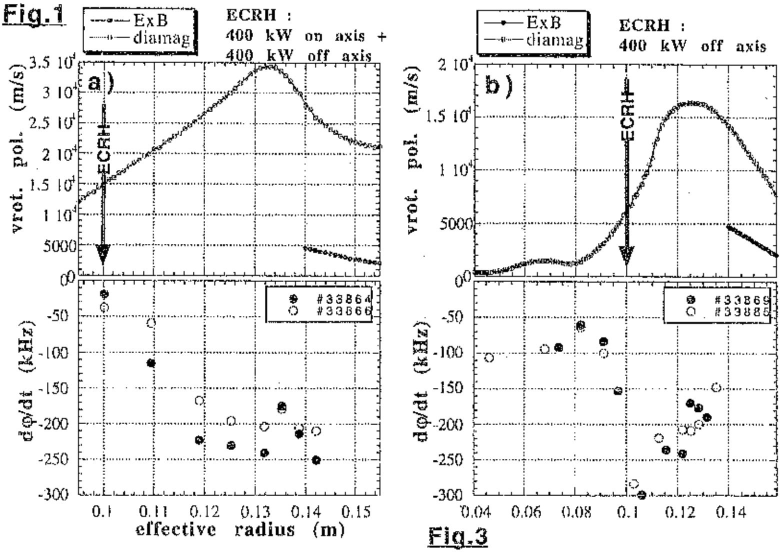

Fig. 1: Radial profiles of poloidal plasma rotation (ExB-component obtained from spectroscopy and diamagnetic drift) and of the phase drift for two types, a), b) of ECRH heated discharges.

Fig. 2: Frequency shift of the reflected signal as a function of cutoff layer position for discharges with normal and inverted magnetic fields. Plasma rotation changes as B is inverted while all other plasma parameters are kept constant.

Fig.3: Time traces of reflectometer phase and amplitude for positive and negative B-fields. The asymmetry of phase and amplitude signals changes sign as the magnetic field is reversed.

Fig.2

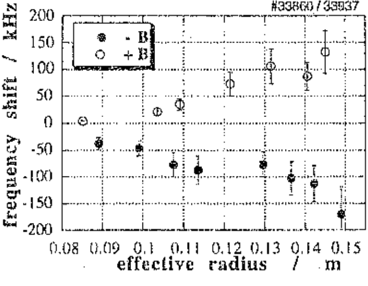

Fig.3