Poloidal velocity of MHD modes at the edge of the ASDEX Upgrade tokamak

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1. Introduction

The presence of Magneto-HydroDynamic (MHD) instabilities is one of the major limitations on the performance of magnetic confinement devices. In particular, plasma rotation can influence the stability of MHD modes. Consequently, the understanding of the physics mechanism that determine the rotation frequency of the MHD modes in the plasma rest frame is of key importance as a way of controlling MHD activity. On ASDEX Upgrade (AUG), a dual channel (Q-band: 33-49.2 GHz and V-band: 49.4-72 GHz) fast frequency hopping heterodyne O-mode microwave reflectometer is installed on the Low Field Side of the tokamak [1]. The Q and V band channels have close probing frequency range and a 32 cm poloidal separation of their antenna, which allow the determination of the poloidal velocity of MHD modes over a limited radial range. In this paper, the temporal evolution of the poloidal velocity of Quasi-coherent (QC) modes at the edge will be presented and compared with the electron diamagnetic drift and the $E \times B$ velocity.

2. Technique

In AUG, by setting the two launch frequencies approximatively the same a measurement of the poloidal correlation and rotation of MHD modes such as QC modes and magnetic island at the edge can be obtained. Here, the probing frequency of the Q and V band channels were fixed at 49.2 GHz and 49.4 GHz respectively. The 200 MHz frequency difference ensures no cross contamination between the respective reflectometer receivers but, is sufficiently small to ensure that the two channels reflect from approximatively the same density cutoff layer (in particular in the steep gradient region). The essential requirement is that the measurement separation (in this case the antenna line-of-sight separation,d_{sep}) must be smaller than the poloidal correlation decay length L_p. For MHD modes L_p is of the order of tens centimeters, while for broadband turbulence L_p is of the order of a few centimeters, i.e smaller than the $d_{sep} \simeq 25\ cm$ evaluated at the plasma edge.

In the frequency domain, the poloidal velocity can be deduced from the corresponding rate of the cross-phase change $\frac{d\theta_{QV}}{df}$ as follows: $v_{pol} = \frac{2\pi * d_{sep}}{\frac{d\theta_{QV}}{df}}$. In the time domain, the Q and V signals are filtered at the mode frequency and the time value corresponding to the maximum of the correlation coefficient $C(\tau)$ gives the time lag (τ_l) between the two signals.

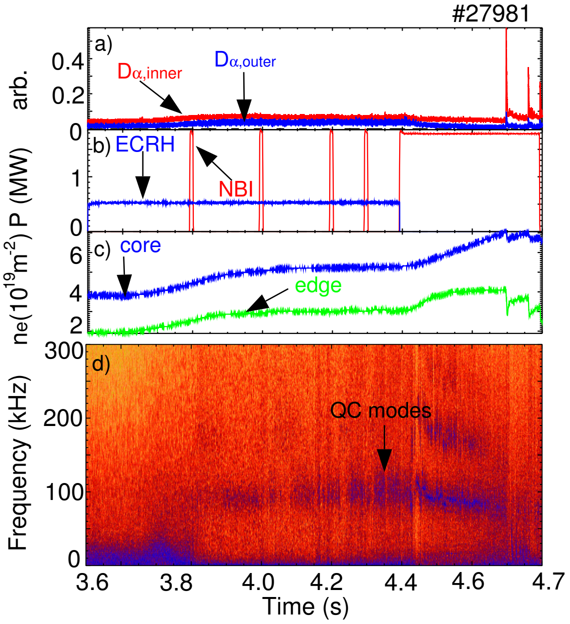

Figure 1: Time traces of (a) D_α, (b) the NBI, ECRH heating power (PNBI, PECRH) and (c) the edge and core electron density from DCN with time-frequency spectrogram of (d) FLQ-I reflectometer for shot #27981

3. Definition of MHD mode rotation

Magnetic perturbations are aligned along the magnetic field lines and so only the velocity component normal to the total magnetic field contribute to the Doppler shifted mode frequency observed on magnetic and reflectometer signals [2]. Various assumptions can be considered for the determination of the rotation frequency f_0 of different MHD modes in the plasma rest frame [3]:

$$f_0 = f_{LAB} - nf_{tor} \quad (1)$$

$$f_0 = f_{LAB} - nf_{tor} + mf_{pol} \quad (2)$$

$$f_0 = f_{LAB} - nf_{tor} - mf_{e,dia} \quad (3)$$

$$f_0 = f_{LAB} - mf_{E\times B} \quad (4)$$

$$f_0 = f_{LAB} - mf_{E\times B} - mf_{e,dia} \quad (5)$$

where n and m are the toroidal and poloidal mode numbers, f_{LAB} the frequency of the mode in the laboratory frame of reference, $f_{tor} = v_{tor}/(2\pi R)$, $f_{pol} = v_{pol}/(2\pi r)$, $f_{E\times B} = v_{E\times B}/(2\pi r)$ and $f_{e,dia} = v_{de}/(2\pi r)$ are the frequencies deduced from the toroidal velocity v_{tor}, the poloidal velocity v_{pol}, the $E \times B$ velocity $v_{E\times B}$ and the electron diamagnetic velocity v_{de} respectively at the major radius R (and minor radius r) where the mode is located.

In the plasma core, the rotation of MHD modes is associated with the toroidal rotation frequency v_{tor} when strong NBI momentum input is applied as observed for example in JET [4] and illustrated by Eq. 1. In AUG, the diamagnetic drift frequency contributes greatly to the mode frequency in the laboratory frame of reference [2,3] and assumption 3 is considered. At the plasma edge, the toroidal rotation is low and so the contribution of the poloidal rotation, the diamagnetic drift velocity and the weighting factor m/n

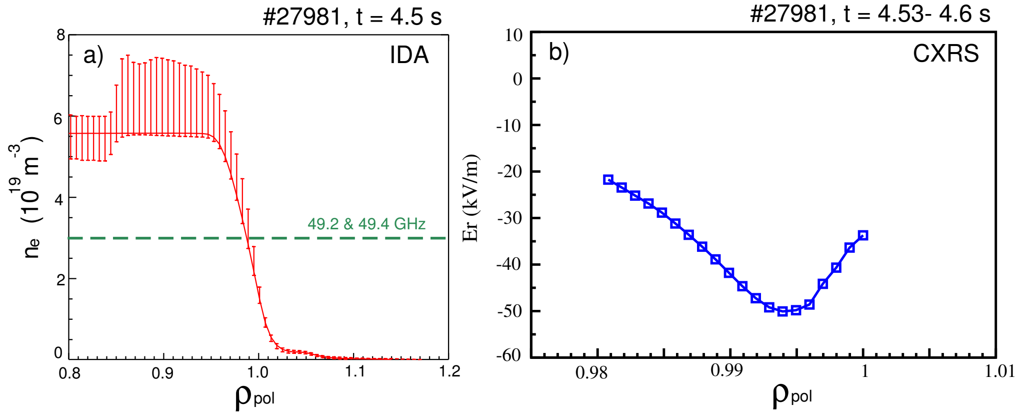

Figure 2: (a) ne profile from IDA at $t \simeq 4.5$ *s and (b) Er profile from CXRS in the time interval* $t = 4.53 - 4.6$ *s for shot #27981.*

becomes significant as represented by Eqs. 4 and 5. The perpendicular flow velocity of the electrons is given by $v_{\perp,e} = v_{E\times B} + v_{de}$ and is linked to Eq. 5.

4. Experimental results

In AUG H-mode discharges, at low heating power, different broadband frequency modes (20 kHz, 40 kHz and 90 kHz) similar to the Washboard mode observed at JET [5] are present in magnetic signals. Figure 1 shows the time traces of the D_α, core and edge line integrated density, the applied ECRH and NBI power with the time-frequency spectrogram of the Q Inphase (FLQ-I) signal for a H-mode discharge. The I-phase characterized by the appearance of oscillation on reflectometer signals [6] starts at around $t \simeq 3.8$ s when the density increases and the L-H transition occurs at $t \simeq 4.4$ s. The reflectometer data displays the 90 kHz QC modes in the pedestal region during the I-phase and H-mode up to $t \simeq 4.7$ s. In I-phase the QC mode is intermittent and coincident with the oscillations while just after L-H transition the mode seems stronger and is continuous. Figure 2 displays the density profile provided by Integrated Data Analysis (IDA) using DCN and Lithium Beam (LID) diagnostics with the position of the density cut-off layer and the E_r profile obtained by Charge Exchange Recombination Spectroscopy (CXRS) [7]. A high spatial resolution of E_r profile is deduced through a scan of the separatrix position in the time interval $t = 4.53 - 4.6$ s, the minimum $E \times B$ velocity is approximatively 20-25 km/s considering a magnetic field on-axis of 2.5 T.

Figure 3 (a) shows the temporal evolution of the electron diamagnetic velocity at the mid-pedestal as well as the poloidal velocity of QC mode and an edge (m=7, n=2) magnetic island (MI) at $f \simeq 17$ kHz using both coherence and cross-correlation techniques. The pressure gradient was calculated using the pressure profiles from IDA and combining Electron Cyclotron Emission, LID and DCN data [8]. Figure 3 (b) and (c) display the divertor current and the time-frequency of the FLQ-I signal, respectively. The poloidal velocity of QC was calculated only for $n = 3, m = 12 - 14$ with a mode frequency of approximatively 90 kHz. For similar discharges, the radial mode structure of QC shows a maximum in the edge region at around mid-pedestal [9]. Here, the QC modes rotate in the electron diamagnetic drift direction with a speed very similar to the $E \times B$ and the electron diamagnetic velocities within the error bars. Comparing with the mode numbers given by magnetics, we find $mf_{E\times B} \simeq 90\ kHz$. Some drops on the QC poloidal velocity seem to be related to the appearnce of "mini-ELMs" on the divertor current signal. The poloidal velocity of MI is obtained using the cross-correlation method with a narrow pass-band filter, in this case the coherence technique is not suitable due to the limited number of points for the determination of the cross-phase rate. The edge MI appears after the sawtooth crash at $t \simeq 4.505\ s$ and has a different radial structure than QC modes as indicated by the different mode numbers. Here, MI is rotating in the ion diamagnetic direction.

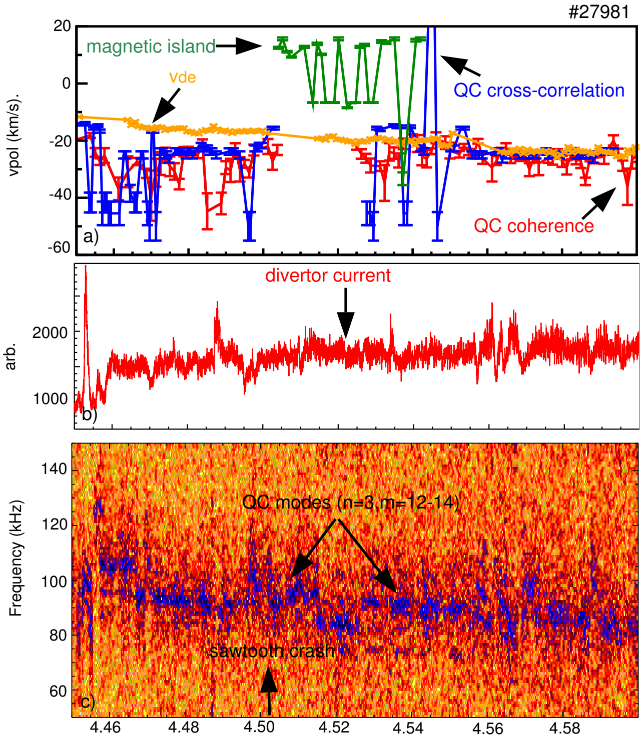

Figure 3: Temporal evolution of (a) v_{pol} for QC modes and MI as well as v_{de} with time traces of (b) inner divertor shunt current and (c) time-frequency spectrogram of FLQ-I signal for shot #27981.

5. Conclusions

The poloidal velocity of MHD modes such as QC and MI have been deduced using poloidal correlation reflectometry for the first time in the ASDEX Upgrade tokamak. The QC poloidal velocity was compared with the electron diamagnetic and $E \times B$ velocities and shows good agreement. At the edge, E_r is dominated by the electron diamagnetic velocity and so $v_{E\times B} \simeq v_{de}$. The experimental results suggest that the QC rotation is related to assumptions (3) and (4).

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