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Radial propagation of poloidal plasma velocity changes in the stellarator TJ-II measured by reflectometry

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Abstract

The radial origin of the velocity shear layer in TJ-II is investigated using two-channel reflectometer measurements. The analysis is done using the reconstructed phase of the complex amplitude signal obtained by the IQ-detector. Several discharges with modulated density, each one crossing twice the so-called critical density, are analyzed. The reversal of the velocity at the critical density is found to have its origin at an intermediate position $\rho \approx 0.75$. In biasing discharges, the capability of the reflectometer to detect the radial position of the velocity shear layer with high accuracy is used to obtain the radial propagation velocity of the perpendicular rotation velocity changes.

Introduction

The two-channel fast frequency hopping reflectometer system installed at TJ-II [1] (Fig. 1) operates in the frequency range of $f = 33 - 50$ GHz, covering the whole gradient region in ECRH-discharges. The system is not perfectly aligned to the flux surfaces, resulting in doppler shifted asymmetric spectra [2] and phase runaway. Although it is not possible to obtain absolute perpendicular velocity values, one is able to extract the direction of the perpendicular velocity by means of spectral and phase analysis. In stable discharges, where turbulence broadening of the power spectrum is constant, relative changes of the poloidal velocity can be monitored. When fixed frequencies are used in both channels and a constant gradient is assumed or verified (e.g. by measurements of the density profile by the AM reflectometer), the radial propagation of perpendicular velocity changes can be monitored.

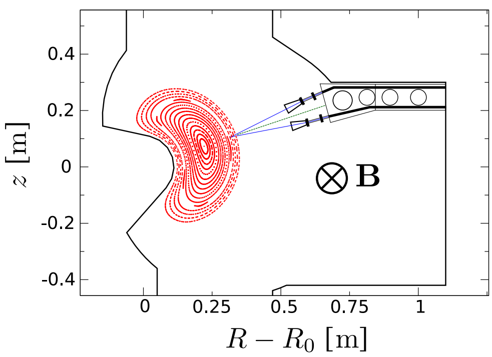

Figure 1: Sketch of the reflectometer system installed at TJ-II. Vessel walls (black) and closed flux surfaces (red) are also shown.

Experimental results - Density modulation

In TJ-II, a velocity shear layer develops spontaneously above a so-called critical line-averaged density [3]. In Fig. 2, the time traces of the line density $\bar{n}_e$ (a), the center of gravity of the power spectra $\bar{f}$ of the two reflectometer channels (b) and their reconstructed phases ϕ c) are shown.

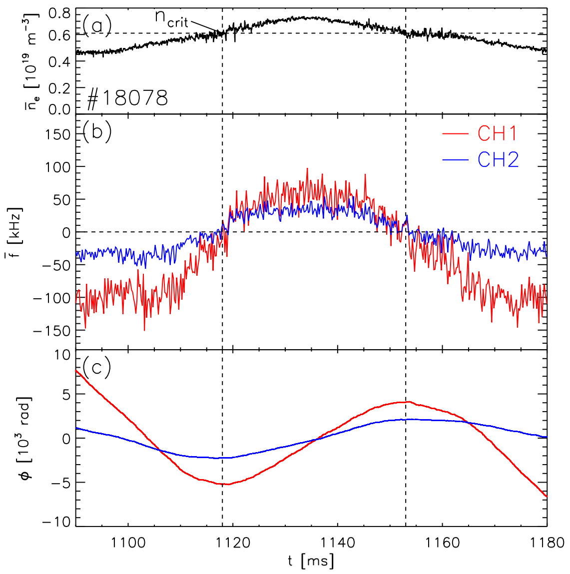

Figure 2: Time traces of (a) line density $\bar{n}_e$, (b) center of gravity of the power spectra and (c) reconstructed phase. Above the critical density n_{crit}, the mean frequencies are positive, as is the slope of the reconstructed phase.

If the line density $\bar{n}_e$ is above the critical density n_{crit}, the mean frequencies and the slope of the reconstructed phase of the two channels are positive, which corresponds to a poloidal velocity in the electron-diamagnetic direction. In a series of discharges where the density was modulated as shown in Fig. 2 (a), the frequencies of the two reflectometer channels were held fixed during the discharge, but changed on a shot-to-shot basis in order to measure at different radial positions. The time instant when the poloidal velocity reverses sign at the corresponding reflectometer channel can be extracted by searching for the minimum in the reconstructed phase while the density is increasing, or by searching for the maximum while the density is decreasing. The delay between the two channels $\Delta t = t_{\mathrm{CH1}} - t_{\mathrm{CH2}}$ is negative when the velocity reversal occurs first at channel 1 and vice versa.

The values obtained for Δt are plotted on the lefthand-side of Fig. 3. The radial positions of the measurements are determined using the density profiles from AM reflectometry. Orange points refer to the part of the discharge where the density crosses from below to above the critical density (emergence of the shear layer). The continuous line is a polynomial fit to the data. All time delays where $\rho > 0.76$ are positive, meaning that the velocity reversal is first noted by the inner reflectometer channel. On the contrary, the time delays with $\rho < 0.76$ are negative, hence it is the outer reflectometer channel which first detects the velocity reversal. If the perpendicular velocity is assumed to be dominated by the radial electric field, this can be interpreted as follows: when the density rises, the plasma potential starts to become hollow at $\rho \approx 0.76$, and this potential drop grows, expanding radially. For the case with decreasing density (green points with corresponding polynomial fit), the contrary takes place: the previously developed drop contracts when the line density crosses the critical density from above and the former potential profile is restored. This process is schematically illustrated on the righthand-side of Fig. 3, where the plasma potential profile is drawn for $\bar{n}_e < n_{\mathrm{crit}}$ (upper line), shortly after passing the critical density (middle line) and when the shear layer is completely established (lower line). As

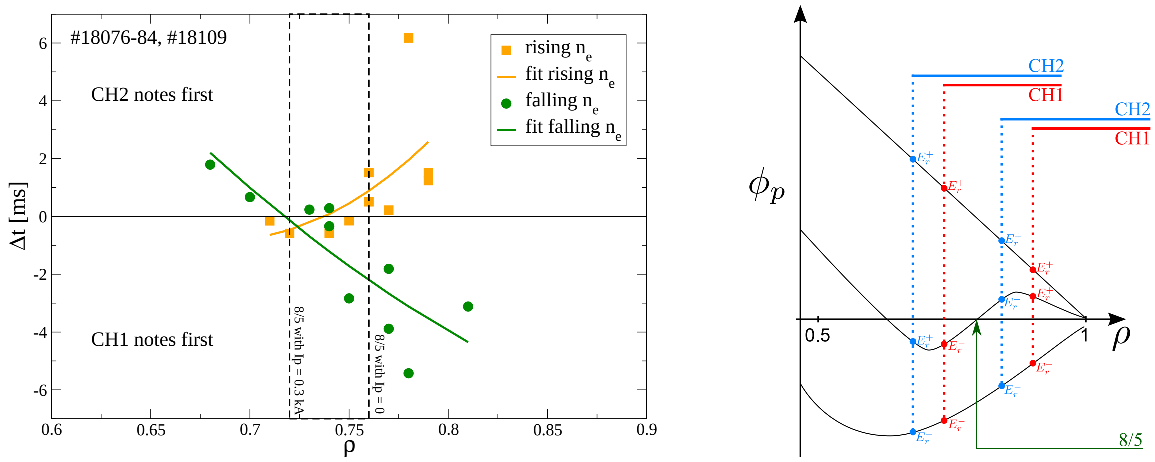

Figure 3: *left:* Time delays Δt between channel 1 and channel 2 when the density rises (orange points) or falls (green points). The lines are polynomial fits to the data. The vertical dashed lines show the 8/5-rational for a currentless plasma $I_p = 0$ and a plasma with $I_p = 0.3$ kA. *right:* Schematic drawing of the plasma potential profile before the shear layer develops (upper line), while crossing the critical density (middle line) and when the shear layer is completely established (lower line). For details refer to the text.

the shear layer develops, channel 2 notes the reversal of the poloidal velocity first if the measurement is at large ρ. Further inside the plasma, channel 1 detects the velocity shear first. When the shear layer is completely established, both channels measure negative poloidal velocities, independently of their positions in the plasma. This behavior resembles the one reported in [4], where a qualitative physical explanation in terms of total momentum conservation is given.

It should be noted that the radial origin of the velocity shear, as detected by the reflectometry measurements presented here, coincides with the position of the 8/5-rational. On the lefthand-side of Fig. 3, the 8/5-rational is indicated by vertical dashed lines for $I_p = 0$ and $I_p = 0.3$ kA, the toroidal current measured by Rogowski-coils. The displacement was calculated using $\Delta(\iota/2\pi) = (\mu_0 R I_p)/(2\pi a^2 B_0)$, following [5]. As of now, we do not have a physical explanation for this phenomenon. Further experiments moving the rational to other radial positions are planned to investigate the role of the 8/5-rational.

Experimental results - Biasing

In Fig. 4 the mean frequencies and the reconstructed phases for the two reflectometer channels in two discharges with biasing are shown. Biasing is applied at $t - t_{\text{Bias}} = 0$ ms. In the upper plot, the mean frequencies of channel 1 (red linespoints), measured at $\rho = 0.85$, become negative as soon as biasing starts. This corresponds to a poloidal plasma velocity in the ion-diamagnetic direction. The inner channel 2 (blue linespoints), measuring at $\rho = 0.79$, is not as clearly affected, the poloidal rotation preserves the electron-diamagnetic direction. The reconstructed phase signals (continuous lines) behave accordingly. Hence the radial position of the velocity shear is located between $\rho = 0.79$ and $\rho = 0.85$, which are separated 7.2 mm.

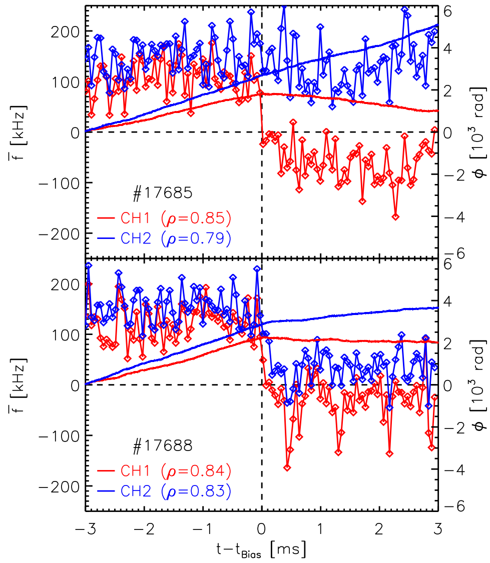

Figure 4: Mean frequencies (linespoints) and reconstructed phases (continuous lines) for discharges with biasing. For details refer to the text.

In the lower plot, both channels are almost equally affected, but the plasma at $\rho = 0.83$ keeps rotating in the electron-diamagnetic direction, while it rotates in the ion-diamagnetic direction at $\rho = 0.84$. Hence, the poloidal velocity shear is located between $\rho = 0.83$ and $\rho = 0.84$, which are 1.3 mm apart. It takes the velocity alteration approximately 130 μs to get from one channel to the other, resulting in a radial propagation of poloidal velocity changes of $v \approx 10$ ms^{-1}.

Discussion

By means of two-channel reflectometry measurements in the stellarator TJ-II, the radial origin of the velocity reversal when crossing the critical density was investigated. It was found that this velocity reversal originates from $\rho \approx 0.75$. Close to the critical density, the plasma potential profile starts to change at the measured radial position. Hence the $E \times B$-velocity changes sign there first and the reversal expands radially until the velocity shear is completely established. The origin $\rho \approx 0.75$ coincides with the radial position of the 8/5-rational.

In future measurements, this phenomenon will be further investigated by changing the magnetic field configuration, i.e. moving the rational to different radial positions.

Besides, the capability of reflectometer measurements to give detailed information on the radial position of the velocity shear in biasing discharges was illustrated. Using either spectral or phase analysis, the radial position of the shear can be determined with high accuracy. The radial propagation velocity of the perpendicular rotation inversion is of the order of 10 ms^{-1}.

The influence of heating power on the poloidal velocity will be intensely studied in the future. Since the formation of the velocity shear depends fundamentally on the collisionality [6], modulation of the heating power is a perfectly suited means to study the radial propagation of poloidal velocity changes in TJ-II.

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