

Reflectometry Measurements of Density Fluctuations under different Plasma Conditions at TEXTOR

A. Krämer-Flecken, H.R. Koslowski
Institut für Plasmaphysik Forschungszentrum Jülich GmbH
EURATOM Association, Trilateral Euregio Cluster
52425 Jülich, GERMANY

V. Dreval, S. Soldatov
Nuclear Fusion Institute, Kurchatov Institute, 123128 Moscow, RUSSIA

1 Introduction

At the TEXTOR tokamak ($R_0 = 175\text{cm}$, $a = 46\text{cm}$) an O-Mode correlation reflectometry system in the frequency range $26 \leq f \leq 37\text{GHz}$ has been installed and operated [1]. The correlation measurements of density fluctuations are provided by three antennas, one is located in the equatorial plane the two others directly below and above the first one. The upper and lower antenna enclose an angle of 13° . All three antennas are located on the low field side in one poloidal cross section. The system allows the measurements of density fluctuations up to 250kHz . Also the measurement of the poloidal velocity component of the density fluctuations can be done [2]. This paper describes the results obtained in different plasma regimes.

2 Measurements of poloidal velocity component

At TEXTOR the measurements of the poloidal velocity component were performed for different heating scenarios. We use a discharge with a density ramp or several discharges whereby the line averaged density was increased on a shot to shot basis. Due to the pre-programmed density ramp the reflection layer moves slowly outward and allows the measurement of the poloidal velocity component at different radial positions.

In our studies we distinguish between OH- and neutral beam heated L-mode plasmas. TEXTOR is equipped with two tangential neutral beam injectors (in Co- and Counter- directions)

having each a power of $P = 1.2\text{MW}$, two ICRH antennas delivering $P = 1.5\text{MW}$ each and a gyrotron with $P = 300\text{kW}$. The influence of the different heating devices on the poloidal velocity component is discussed in the following section.

2.1 OH and co-NBI heated plasmas

For this study also the effect of the reversal of the plasma current was taken into account.

In OH-plasmas (green squares in fig. 1) we found a poloidal velocity component of $v_{pol} = 6\text{km/s}$ at $R = 215\text{cm}$. With the inward movement of the reflection layer the velocity decreases linearly with $dv/dr = 0.17\text{km}/(\text{s cm})$. At $R = 190\text{cm}$ we calculate $v_{pol} = 2\text{km/s}$. The displayed results contain OH-discharges from three month of TEXTOR operation and show the good reproducibility of the measured data. **In neutral beam heated discharges** (red squares in fig. 1) the additional toroidal momentum leads to an additional poloidal velocity component. As a result the the sign of the poloidal velocity change for $r \leq 209\text{cm}$. At $R = 216\text{cm}$ the poloidal velocity of the turbulence is the same as in the OH-regime. This is an indication that the plasma edge is not much influenced by the neutral beam injection. The region $208.5 \leq R \leq 212.0\text{cm}$ is inaccessible for measurements (grey rectangles in fig.2 and 3) because the because the time delay of the fluctuations becomes greater than $13 - 16\mu\text{s}$. In this region the lifetime of the fluctuation is smaller than the time needed by the fluctuation to move across the reflecting surface within

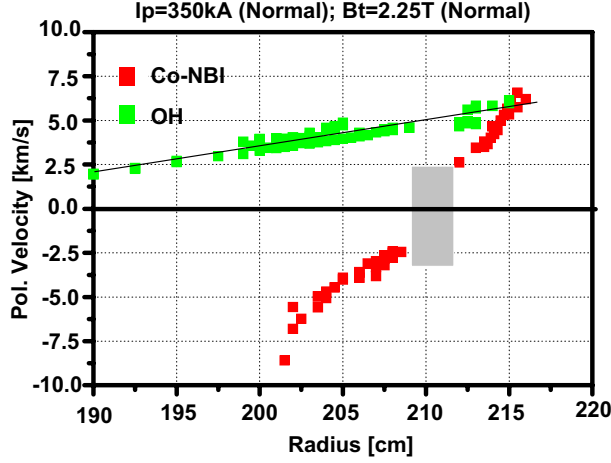


Figure 1: Poloidal velocity for OH and co-NBI discharges with normal plasma current direction

a poloidal angle of 13° . For reflection layers deeper in the plasma the velocity increases from -2.5km/s to -7.5km/s at $R = 202\text{cm}$.

Plasmas with reversed current (purple squares in fig. 2) show a similar behaviour except of a change in signs. The measured delay is negative at $R \geq 213\text{cm}$ and therefore also the poloidal velocity. At $R = 219\text{cm}$ we measured $v = -8\text{km/s}$. In the case of co-NBI (now with the NI-2) we observed a fast increase in the velocity with an inward moving reflection layer. For $R \leq 210\text{cm}$ the measured poloidal velocity is positive. Due to the small radial range which was measured a tendency for the change of the poloidal velocity could not be given. Comparing both cases with co-injection with normal and reversed current direction respectively we found a small asymmetry in the radial position where the poloidal velocity changes sign. In the case of NI-1 co-injection the region where the poloidal velocity changes sign is located 1.5cm further inside the plasma as in the case of NI-2 co-injection.

Counter-injection with normal plasma current direction was also analyzed in the range $203 \leq R \leq 210\text{cm}$. However in this case the reflection layer could not be followed up to $R = 215\text{cm}$, because the data base is very small. As expected from symmetry considerations we measured a positive delay and therefore positive velocities between $7.5 \leq v \leq$

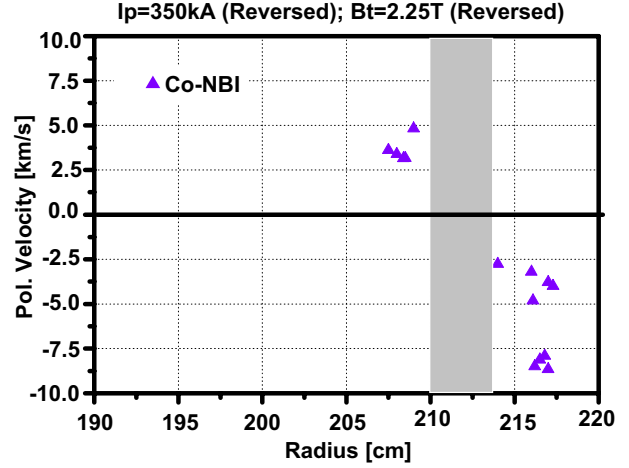


Figure 2: Poloidal velocity for co-NBI with reversed plasma current direction

5 km/s . Furthermore we found a decreasing velocity with an inward moving radial position with a more steep slope than in the OH-case. Also the absolute measured values are larger compared with OH-plasmas.

2.2 Poloidal velocity during power scan with ICRH

Several discharges with different ICRH-power were analyzed. The ICRH-power was always injected into the same ohmic target plasma. The plasma current direction was normal. In these discharges we obtained positive poloidal velocities at $R = 214\text{cm}$. Since the reflection layer was nearly constant the behaviour of the poloidal velocity during a power scan could be analyzed. Within the error bars we found a linear increase from $v_{pol} = 4.8\text{km/s}$ in ohmic plasma to $v_{pol} = 7.8\text{km/s}$ at 1.2MW ICRH power. A comparison of the ICRH data with those obtained from co-NBI at $P = 1.2\text{MW}$ yield 25% smaller values (see fig. 3).

2.3 Poloidal velocity during ECRH-heating

The effect of the ECRH on the poloidal velocity was studied in the discharge #90232. The deposition radius of the ECRH was located at $R = 192\text{cm}$. The low density of the discharge $\bar{n}_e = 1.5 \times 10^{13}\text{cm}^{-3}$ yields a reflection at $R = 205\text{cm}$. The gyrotron ($P = 300\text{kW}$, $\Delta t = 200\text{ms}$) heats the electrons only.

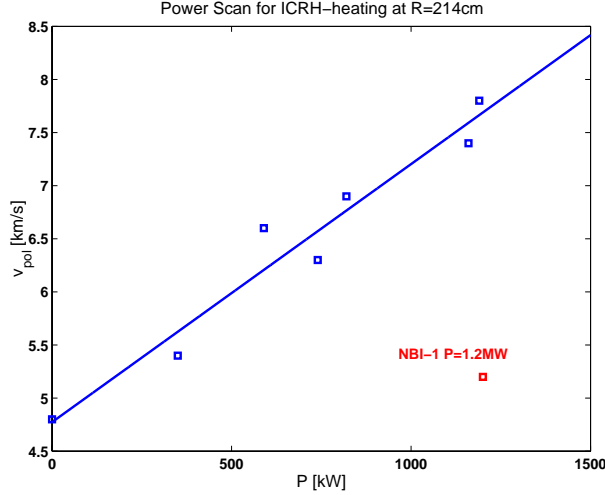


Figure 3: Power Scan of the poloidal velocity. For comparison the data for co-NBI at $P = 1.2MW$ is shown.

With the onset of the gyrotron the poloidal velocity decreases from -3km/s to -6km/s (fig. 4). However the poloidal velocity changes not immediately but on the same time scale on which the plasma profiles change, mainly the electron temperature. To establish the new profile shape it takes approximately one confinement time ($\Delta t = 50\text{ms}$). However the correlation coefficient decreases only slightly during ECRH-heating but immediately with the onset of the gyrotron. In addition the density fluctuation spectrum is more peaked in the case of additional ECRH heating than in the phase of NBI-injection only. We found an increase of the fluctuation amplitudes below $f = 50\text{kHz}$.

3 Reflectometry during the β -limit in RI- mode discharges

The installed reflectometry systems is in principle not able to measure deep in the plasma during RI-mode operation at TEXTOR. Due to the high central density the reflection layer is located at $218 \leq R \leq 220\text{cm}$. However experiments have shown systematic changes in the fluctuation spectrum in those plasmas. The approach of the β -limit is characterized by a sudden loss in the diamagnetic energy and a fast drop in the line averaged density of 10–20%. To establish the RI-mode Ne-injection is used to radiate equally the power. On the way

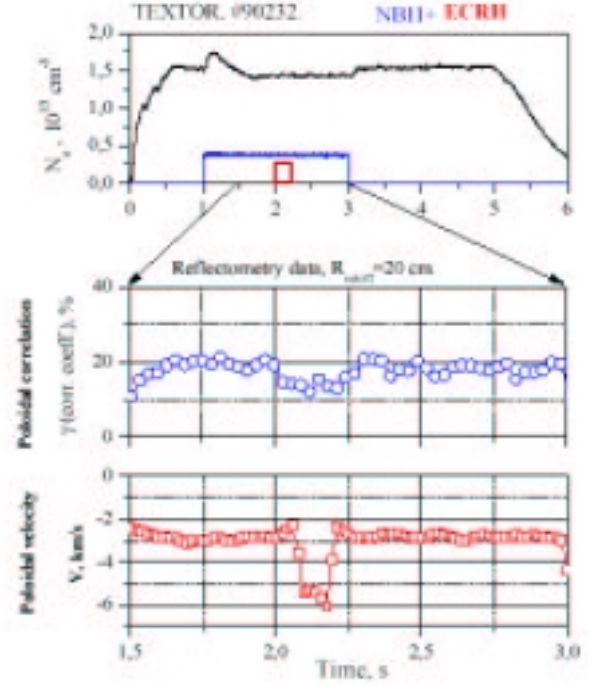


Figure 4: Poloidal velocity during ECR-heating (a) and the density fluctuation spectrum during the NBI- and ECRH-phase

to achieve an RI-mode early neutral beam and ICRH-heating is needed. As long as only co-NBI was applied the poloidal component of the plasma velocity was measured at $R = 214\text{cm}$. We observe a delay of the measured fluctuations of $\approx 10\mu\text{s}$. This corresponds to a velocity of $v_{rot} = 4.4\text{km/s}$. As soon as the counter injector is switched on, the reflection layer moves further outside to $R = 220\text{cm}$. Since the second neutral beam injects in counter direction with respect to the first one, the rotation is strongly reduced and the cross correlation coefficient measured by reflectometry becomes very small. The life time of the fluctuations becomes smaller as the time needed to move along the distance between the two antenna and a further quantitative analysis of the poloidal velocity is not possible.

Further information is obtained from the density fluctuation spectrum of every single antenna. With co-NBI only the obtained profile is symmetric. With the onset of the counter-NBI at $t = 1.0\text{s}$ the fluctuation spectrum changes (see fig. 5). Within the first 100ms of NI-2 the spectrum peaks at low frequencies. Shortly after the onset of the Ne-injection

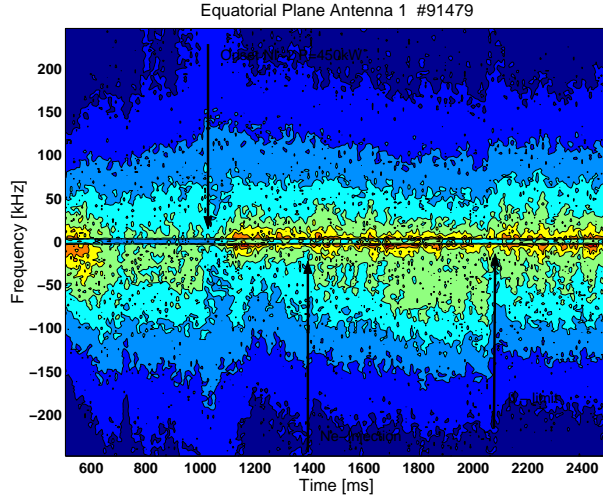


Figure 5: Density fluctuation spectrum of a single antenna. The onset of the mode activity at $t = 1.7$ s is strongly correlated with the broadening of the spectrum.

at $t = 1.4$ s the fluctuation spectrum becomes broad and asymmetric. Together with the Ne-injection the density rises and at $t = 1.7$ s MHD-mode activity most likely a global kink mode [3] is observed in the plasma centre with $f \approx 3$ kHz (see fig.6) and the plasma edge. The mode frequency increases towards the β -limit. The onset of the kink mode correlates with a broadening of the density fluctuations spectrum. The appearance of the β -limit stops this mode abruptly and the spectrum becomes symmetric again. This behavior is of interest since the fluctuation spectrum measured at the plasma edge changes more less at the same time the collapse in the plasma centre happened. A new localized MHD-mode appears after the β -limit however this cannot be resolved by the reflectometer.

4 Conclusion

The reflectometry at TEXTOR was used in different plasma scenarios to study the poloidal velocity component at different radial positions. We found differences between OH and neutral beam heated discharges. The reversal of the plasma current changes the sign of the calculated poloidal velocity. However an asymmetry was found in the position of the transition from positive to negative poloidal velocities.

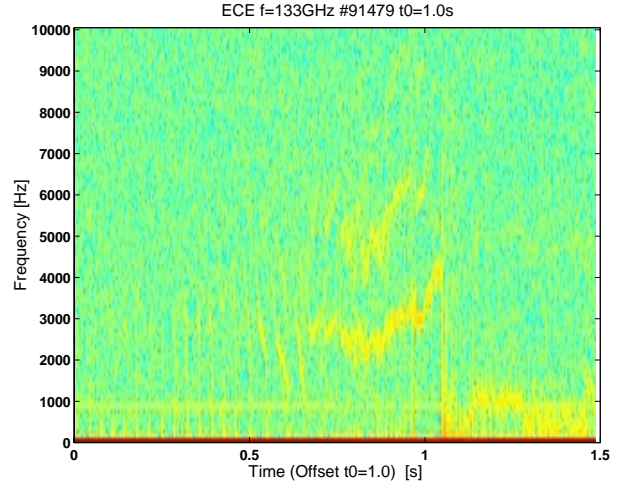


Figure 6: Spectrogram of ECE-data showing the onset of the mode at $t = 1.7$ s. Note that for the x-axis an offset of $t = 1$ s must be added

Furthermore the behaviour of the velocity during the ECRH-operation showed that the poloidal velocity depends on the plasma profile. In the β -limit discharges a correlation with the MHD-activity in the plasma centre and the fluctuation spectrum measured at $R = 220$ cm was found.

In the future TEXTOR will be equipped with a further reflectometer working at $f = 70$ GHz. In addition the antenna geometry will be modified for a better measurement of the poloidal velocity and to allow also the measurements of the toroidal velocity component [4].

References

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