Study of density turbulence and coherent mode activity in W7-AS by microwave reflectometry

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Abstract - In the context of transport investigations different heating scenarios have been studied in W7-AS. When the plasma is heated by NBI (pure as well as combined with ECRH) the signals from the microwave reflectometer show coherent mode activity in the frequency range of 20 to 90 kHz depending on the iota profile. These modes have been observed for all the radial positions probed by the reflectometer and are identified as global Alfvén modes.

Experimental system - At W7-AS (R = 2 m, a < 0.17 m, 5 field periods, modular stellarator coil system) a reflectometer is installed [1,2] for density profile and fluctuation measurements. The system uses X-mode propagation in the W-band (75-110 GHz) for probing radial positions corresponding to densities between 1 to 6 10^{19} m^{-3}. At the toroidal position where the reflectometer is installed the plasma has a nearly elliptical shape with the minor axis along the equatorial plane of the torus. Corrugated horns in combination with elliptical mirrors are used as emitting and receiving antennas resulting in a focused Gaussian beam of 2 cm diameter at the reflecting layer. Heterodyne detection allows to measure phase and amplitude fluctuations separately. An Amplitude Modulation (AM) system [2] integrated into the reflectometer provides a time delay measurement which is used to obtain electron density profile information. This time delay of the signal depends on the cutoff position and on the local density gradient being, in most of the cases, more sensitive to the latter one. Therefore the time delay signal can be considered as a monitor of the local density gradient.

Experimental results - In the context of transport investigations the microwave reflectometer was operated in discharges with different heating scenarios: ECRH, NBI, and combined NBI+ECRH. Two types of discharges are studied in this paper. (1) Plasmas with combined, ECRH (500 kW) and NBI (1.5 MW), heating which show a very high ion temperature, reaching values up to 1.5 keV [3]. (2) Discharges with pure NBI heating with lower injected power (0.5 MW), which reach energy confinement times about twice as large as predicted by neoclassical theories [3]. Both improved confinement scenarios are achieved under low wall-recycling conditions and are characterized by a low edge density and high density peaking factor [4]. Electron density profiles from Thomson scattering and AM-reflectometer for these two types of discharges are shown in Figure 1. The radial positions probed by the microwave reflectometer are between 11 cm and 15 cm. Shots with pure NBI heating and very high energy confinement time show an electron density profile steeper than shots with combined heating (ECRH+NBI) and very high ion temperature.

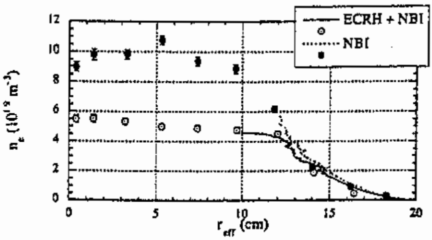


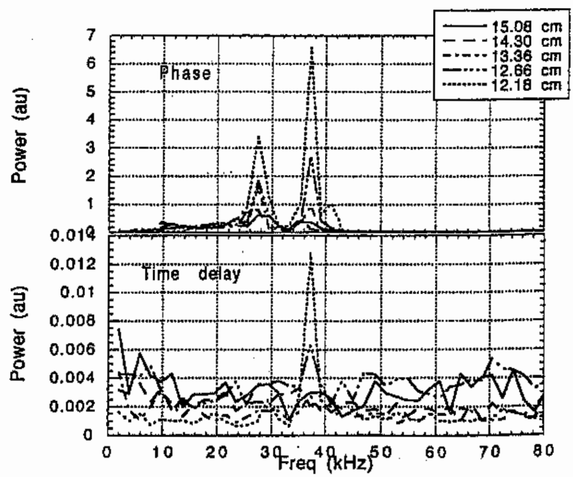
Figure 1: Electron density profiles from Thomson scattering (circles) and from microwave reflectometer (lines) in the discharges of interest: combined ECRH+NBI heating and pure NBI.

In general, if the plasma is heated by NBI (pure as well as in combination with ECRH) the reflectometer signals show coherent mode activity. Other diagnostics (X-ray, ECE, Mirnov coils, etc.) also observe these modes depending on the iota profile, and have been identified as global Alfvén modes [5].

The interpretation of reflectometry phase measurements is complicated by an asymmetry in the phase fluctuation spectra, called „phase runaway" [6]. Under both plasma conditions discused in this paper this effect is several times lower than in pure ECRH plasmas, therefore the measured phase fluctuations mainly can be interpreted in terms of density fluctuations.

Figure 2-a: Phase fluctuation spectra during a purely NBI heated plasma for different radial positions.

Figure 2-b: Time delay spectra during a purely NBI heated plasma for different radial positions.



During pure NBI heating the coherent modes observed by reflectometry appear in the frequency range of 10-40 kHz. As an example Figure 2-a shows the power spectra of the reflectrometer phase. Two different modes with frequencies of 27 kHz and 37 kHz are present simultaneously in the spectra. The frequency of these modes is independent of the radial position probed by the reflectometer (r_{eff} = 11-15 cm) and their amplitude increases towards the plasma centre.

The time delay signal has been measured simultaneously. The dispersive effects, associated with the local density gradient, represent the largest contribution to the measured time delay. Therefore, fluctuations in the time delay signal can be considered as a monitor of the local density gradient. The spectral analysis of this signal, shown in Figure 2-b, does not always show the coherent modes. Only in the most inner radial positions probed with the reflectometer, the highest frequency (f = 37 kHz) coherent mode is seen. This absence of coherent modes in the time delay signal can be interpreted as a movement of the density profile.

During discharges with combined heating, P_{ECRH} = 400 kW and P_{NBI} = 1.5 MW, where the ion temperature reaches values of about 1.45 keV, the frequency of the observed modes is higher than during pure NBI heating, appearing modes up to 90 kHz. Similarly to purely NBI heated discharges, the amplitude of these modes also increases towards the plasma centre and their frequency is constant along all the probed radii. As an example Figure 3-a shows the spectra of the phase signal where several global modes are observed at different frequencies. The coherent mode with the highest frequency appears at 85 kHz in all the probed positions. The spectra of the time delay signal, Figure 3-b, shows this highest frequency coherent mode in most of the radii tested while the lower frequency modes are not observed.

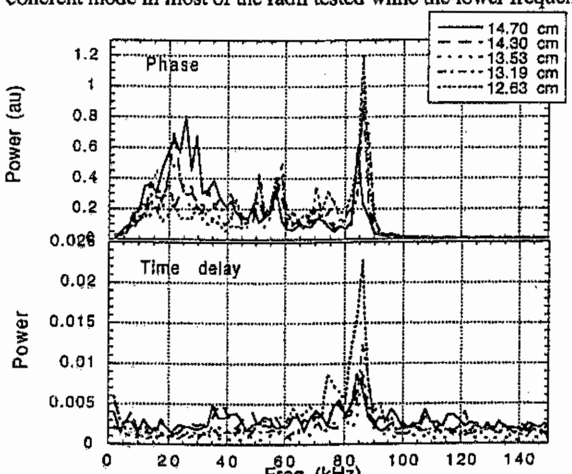


Figure 3-a: Phase fluctuation spectra during a combined NBI + ECRH heating for different radial positions.

Figure 3-b: Time delay spectra during a combined NBI + ECRH heating for different radial positions.

Microwave reflectometer results were also obtained during discharges in which the heating was switched from pure NBI (0.5 MW) to pure ECRH (0.4 MW). In contrast to the purely NBI heated phase in the purely ECRH heated plasma these coherent modes disappear in the reflectometer signal in all of the probed radii, indicating that the heating and not the magnetic configuration is related with the origin of the modes. Similar radial positions were probed by the reflectometer in the two heating scenarios. In the NBI heating regime (Fig. 4-a) a coherent mode with a frequency of about 45 kHz can be observed in all the probed radii while with ECRH (Fig. 4-b) this mode does not appear. The absence of the 45 kHz coherent mode in the ECRH regime has been also observed by other diagnostics, e.g. Mirnov coils as shown the figure 5.

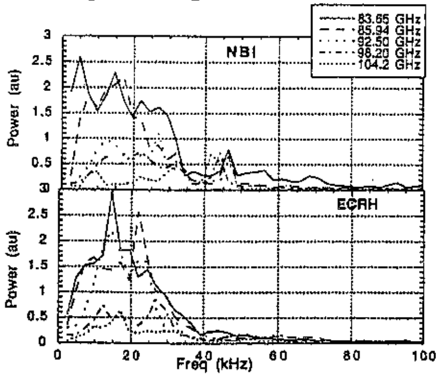


Figure 4-a: Phase fluctuation spectra during a purely NBI heated plasma for different radial positions.

Figure 4-b: Phase fluctuations spectra during a purely ECRH heated plasma for different radial positions.

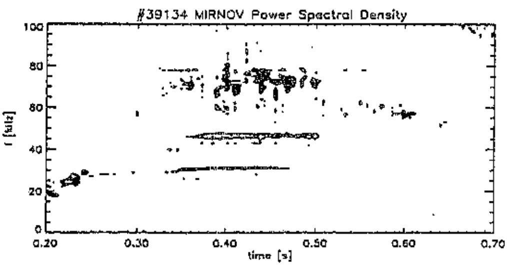


Figure 5: Temporal spectrum evolution of Mirnov coil signal in a shot where the heating was switched from pure NBI to pure ECRH. The 45 kHz coherent mode disappears when the heating scenario is changed at 0.5 s.

In both heating regimes the low frequency broadband incoherent density fluctuations (f < 40 kHz) decrease as positions futher inside are probed. In contrast the power of the 45 kHz coherent mode observed with NBI is nearly independed of the probed positions.

Conclusions - In NBI heated plasmas coherent mode activity is observed which shows up as coherent oscillations in the reflectometer signal if the phase runaway is low. The spectral analysis of the phase signals shows very sharp frequency lines. The modes decay with about 200 μs after NBI is switched-off and their frequencies scale roughly with the Alfvén velocity [5]. They are observed in all the probed radial positions indicating a global mode structure. These observations are in agreement with an interpretation as global Alfvén eigenmodes.

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