CTS observations of NBI-induced instabilities in TEXTOR plasmas

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1. Introduction

Fast ion induced instabilities were observed in TEXTOR by the collective Thomson scattering (CTS) diagnostic. The diagnostic measures scattered probing radiation from the plasma. A 110 GHz 200kW gyrotron is used as source of probing radiation. The scattering signal is sensitive to macroscopic oscillations with wave vector $\mathbf{k}^{\delta} = \mathbf{k}^{s} - \mathbf{k}^{i}$, where $\mathbf{k}^{s}$ and $\mathbf{k}^{i}$ denote wave vectors of scattered and incident radiation, respectively. Using the CTS diagnostic, NBI-induced instabilities (*instabilities* later) were observed in discharges with counter-I_P NBI and with the low-power radial hydrogen diagnostic injector, RUDI [1]. Transient events during the counter-Ip NBI switching-on and -off times were observed. In this contribution, only a phenomenological description is given. A theoretical explanation will be given in a later publication.

Fast ion induced instabilities were found in many machines, e.g. JET [2, 3], TFTR[2], JT-60 [4] and Wendelstein 7-AS [5, 6]. A number of explanations related to very narrow velocity distribution of fast ions were suggested for the observed phenomena [6-9].

In section 2 the experimental setup is described. Section 3 is devoted to the discussion of instabilities observed in different regimes – during flat-top counter-I_p NBI (3.1), transient activity at the counter-I_p NBI switching-on time (3.2) and during flat-top RUDI injection (3.3). In section 4 we discuss the differences in our observations with the observations from another machines.

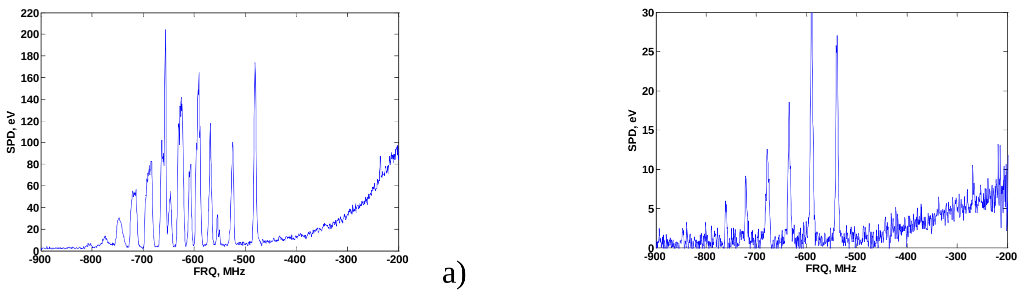
2. Experimental Setup

The CTS receiver on TEXTOR is a heterodyne radiometer with 42 channels with minimum bandwidth of 80 MHz which is too wide to resolve peaks of instabilities separated by 20 – 50 MHz. In order to obtain significantly higher frequency resolution, the receiver was upgraded with a Tektronix Digital Phosphor Oscilloscope (model DPO 7104) with 8-bit dynamical range and sampling rate set to 5 Gsamples/s. The oscilloscope is equipped with 256 MB of fast memory which allows 50 ms of acquisition time. The time trace is analyzed using a spectrogram with a frequency resolution of 0.6 MHz (2^{13} points per window). A complete description of the setup can be found in reference 10. All experiments were conducted in deuterium plasmas with hydrogen NBI at injection energy of 50 keV. The gyrotron was operated with 50% duty cycle (2 ms on / 2 ms off) in order to subtract ECE background. The power of probing radiation was 150 kW.

3. Experimental Results

3.1 Instability during the counter-I_P NBI switching on

TEXTOR is equipped with 2 heating NBIs at a very tangential geometry with a power of up to 1.3 MW. The activity associated with the counter-I_P NBI switching-on appears in the CTS spectra as peaks with frequency separation in the ion cyclotron range of frequencies. Fig. 1(a) shows an average scattering spectrum of a single gyrotron-on time right after the counter-I_P NBI was turned on. The abscissa in all the figures represents frequency shift of the scattered radiation from the frequency of probing radiation. The frequency range between 0 and 200 MHz is covered by the notch filter. Co-I_P NBI was turned on throughout the measurements; the central density (measured by interferometry) was ~$4.2 \cdot 10^{19}$ m^{-3}. The proton cyclotron frequency in TEXTOR plasmas during the CTS experiments varies from 30 MHz at LFS to 54 MHz at HFS. The cyclotron frequency in the center is 40 MHz. All the peaks (except for two with the lowest frequency) which are shown in Fig. 1(a) vanish within 2 ms. Most likely, they correspond to different modes of fast ion-triggered instability. The spacing between the lines varies from 5 to 42 MHz. However, if several different types of instabilities in the same frequency range contribute to the spectral shape, the spacing between the peaks may provide only very limited information. In this discharge both co- and counter-I_P NBI were injected simultaneously at almost maximum possible power: 1.2 MW.



a) b)

Figure 1. (a) Mean CTS spectrum of one gyro pulse closest to the counter-I_p NBI switshing-on time for (a)111528 with P_{NBI} = 1.2 MW and (b) 111802 for P_{NBI} = 0.6 MW.

In discharge 111802 (Fig.1(b)) both co-I_P and counter-I_P NBI were running at 600 kW, plasma density was 5.5 $\cdot 10^{19}$ m^{-3} in the centre, which is around 30% higher than in discharge 111528. In the lower power and higher density discharge, the peaks in the spectrum are arranged more regularly, with the distance between peaks monotonically increasing from from 39 to 50 MHz. These frequencies correspond to the hydrogen cyclotron frequency at a magnetic field in the range 2.6 to 3.3 T. In the given discharges, this magnetic field range corresponds to the plasma centre and the high field side.

3.2 Instabilities during Flat-top operation of the Heating Counter-I_P NBI

Steady-state emission from heating counter-I_P NBI has been observed in many discharges. An example is shown in Fig 2. In this discharge 109172 only the counter - I_P NBI was switched on, PNBI = 1.2 MW. Electron density was less than $3 \cdot 10^{19}$ m^{-3}. In contrast to Fig. 1(a), the distance between the peaks during the steady-state NBI operation decreases monotonically from lower to higher frequencies (in absolute values) from 52 MHz to 47 MHz. In terms of hydrogen cyclotron frequencies it corresponds to a magnetic field in the range 3 to 3.4 T, i.e. the source would be located on the HFS.

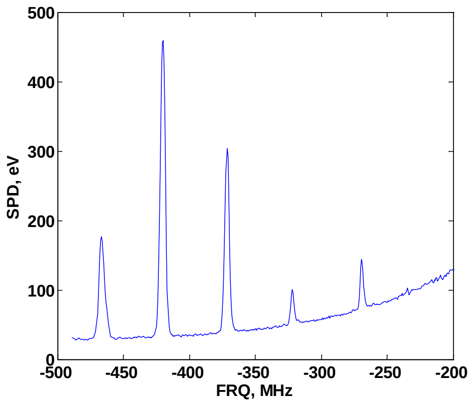


Figure 2. Mean CTS spectrum during the flat-top phase of counter-Ip NBI in discharge 109172 at around t = 1.7 s

In other discharges similar trends have been observed.

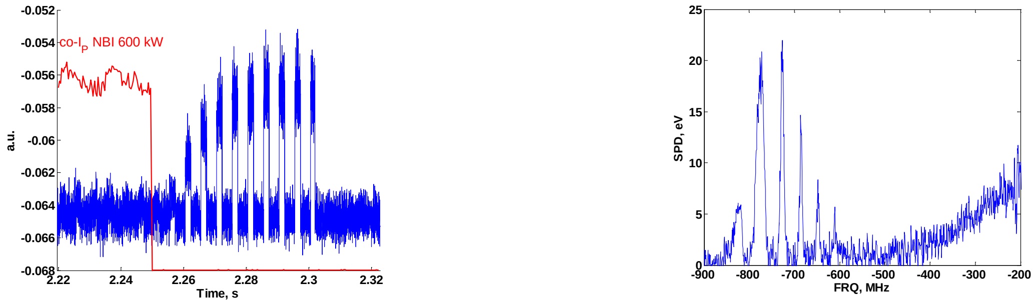
3.3 Instability Triggered by Low Power Diagnostic Beam

The low power (50 kW) radial hydrogen diagnostic beam (RUDI) was used to study the observed instabilities on TEXTOR.

In the discharge 111802, RUDI was on during 600 kW co-I_P NBI. At this period no instabilities-associated activity were detected by CTS.

At the moment when co-I_P NBI has been switched off, the peaks in the CTS spectra start to emerge (Fig. 3(a)). There was no well-pronounced transient activity after the RUDI beam was switched on. During the steady-state RUDI operation, the distance between the peaks in Fig 3(b) increases monotonically with increase of frequency (in absolute values).

The frequency range of peaks separations was 46 to 50 MHz which corresponded to a magnetic field in the range 3 to 3.3 T in terms of proton cyclotron radius, so in this case the emission would come from the HFS.



a) b)

Figure 3. (a) Time trace of the raw CTS signal in one of the receiver channels (#31) sensitive o the signal in the corresponding frequency range in discharge 111802 and the power of co-I_P NBI; (b) Mean CTS spectrum of the steady-state signal due to RUDI operation in discharge 111802 at around t = 2.29 s.

4 Comparison to Previous Observations

The NBI-induced instabilities observed in TEXTOR by CTS have some features which make them different from observations on TFTR, JET and Wendelstein 7-AS. In TEXTOR, the CTS diagnostic detects the signal starting only from ~200 MHz away from the gyrotron frequency due to the notch filter, so it is technically unable to detect the very first harmonics of the ion cyclotron emission (ICE). In contrast to that, ICE on JET and TFTR had rather low frequency and corresponded to maximum first five harmonics of the cyclotron frequency. Secondly, in contrast to previous observations the peaks are not equidistant in frequency, most likely different beams cause different kinds of instabilities. This topic requires future investigation and modeling because the instability is highly dependent on the shape of the distribution function.

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