Further development of reflectometry diagnostics for measurement of
Alfvén Cascades on the JET tokamak

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1. Introduction

A new class of Alfvén Eigenmodes, so-called Alfvén Cascades, was recently observed in
the JT-60U, JET, TFTR and Alcator C-Mod tokamaks. The excitation and observation of
these Alfvén Cascades is important for the diagnosis of advanced plasma scenarios. In
addition to the determination of the magnetic field topology, the time evolution of the
minimum of the safety factor – which is an useful parameter for the triggering of the internal
transport barriers - can be inferred from their measurement. It was shown on TFTR that X-
mode reflectometry could provide more information on the Alfvén Cascades than the external
magnetic pick-up coils generally used for their detection [¹]. On JET a new approach based on
O-mode measurement in the interferometry regime proved to give an unprecedented clear
picture of the Alfvén Cascades [²]. In this paper are discussed the main characteristics of the
technique used and some illustrative results are presented.

2. Description of the fixed frequency multi-channel reflectometer diagnostic on JET

A 12-channel narrow-band reflectometer system probing the mid-plane plasma with the
O-mode polarisation was used for density profile measurement on the JET tokamak [³]. This
system now works with 10 channels at fixed frequencies (from 18.6 up to 69.6 GHz
corresponding to the critical density range 0.43 – 6 x 10¹⁹ m⁻³) and is purely dedicated to
study of the density fluctuations. Each channel uses two Gunn oscillators, whose frequency
difference is maintained equal to 10.7 MHz by a phase-locked loop, for heterodyne detection.
Each channel is also equipped with I/Q detection, thus allowing the determination of the
amplitude and phase signals. I/Q data from up to 7 channels can be acquired with a digital
converter at a frequency rate of 1 MHz and for a maximum of 3s. In addition, another acquisition system offering the possibility of recording all the channels at a frequency rate of 2 MHz during all the discharges was recently implemented.

The advanced scenarios developed at JET generally lead to flat density profiles. In this case it is not possible to probe the core and the high field side regions of the plasma with O-mode reflectometry, since the probing waves cannot be reflected in these regions. This is illustrated on Figure 1, where the various frequencies of our multi-channel reflectometer are compared to the radial profile of plasma frequency for a typical JET discharge. From this figure it can be noticed that only the lowest probing frequencies (those lower than the maximum of the plasma frequency) are reflected by the plasma. This is the conventional use of a reflectometer but in these scenarios with flat density profiles the probing wave is reflected in the extreme edge region of the plasma (in the pedestal region) and consequently no information on the plasma core can be inferred. On the other hand, the probing frequencies higher than the maximum of the plasma frequency propagate without being reflected by the plasma. Reflected by the inner-wall, they come back to the detector after a round trip along the probing line of sight in the whole plasma region. In this situation, the reflectometer acts as an interferometer and all the plasma (including the core and high field side regions) can be probed. As shown in the next section, the interferometry regime proves to be quite efficient to observe MHD modes, such as the Alfvén cascades. Provided that the probing beam is launched perpendicularly to the inner-wall, the reflected beam is especially sensitive to the plasma fluctuations with a probing frequency approaching the plasma frequency.

![Figure 1: Frequencies of the different channels (horizontal lines) of the O-mode reflectometry diagnostic with respect to the plasma frequency at various times.](image-url)
3. Measurements of Alfvén cascades in the interferometry regime

As discussed in [1], the density fluctuations induced by the Alfvén cascades are mainly localised in the high field side region so that only the channels in the interferometry regime (i.e. with probing frequency higher than the maximum of the plasma frequency) could detect them. In Figure 2 a spectrogram (sliding FFT) of the reflectometer “homodyne” signal $a(t) \times \sin(\phi(t))$ at frequency $f = 45.2$ GHz is depicted. From Figure 1, which corresponds to the same plasma discharge, we can notice that the diagnostic is in the interferometry regime during the time of interest (as the probing frequency $f = 45.2$ GHz is always higher than the plasma frequency maximum). Different classes of Alfvén Eigenmodes – such as the Alfvén Cascades (ACs) and the Toroidal Alfvén Eigenmodes (TAEs) in the 40-150 kHz range and the Elliptical Alfvén Eigenmodes (EAEs) in the 300-400 kHz range - can be observed in this spectrogram. In particular, the Alfvén cascades are detected with high time and frequency resolutions, far clearer than from other diagnostics as the magnetic pick-up coils and electron cyclotron emission radiometer. After calibration of the I and Q signals to remove the offsets and the amplitude and phase unbalance, the amplitude and phase signals can be extracted. A picture of the different Alfvén Eigenmodes as clear as in Figure 2 can still be obtained from the spectrograms of the amplitude and phase signals respectively.

![Figure 2: Observation of different classes of Alfvén Eigenmodes from the spectrogram of the homodyne signal (ACs / TAEs in the 40-150 kHz range and EAEs in the 300-400 kHz range)](image)

Due to the high resolution of the interferometry-like measurements, the dynamics of the Alfvén cascades can be assessed. For instance, a clear Doppler shift of the frequency of the Alfvén cascades (up to 300 kHz) induced by the plasma toroidal rotation in the presence of strong neutral beam injection (NBI) heating was observed in [2]. As exemplified in Figure 3,
it was also shown that the Alfvén cascades, usually driven by super-Alfvénic ions accelerated with ion cyclotron resonance heating (ICRH), could also be driven by sub-Alfvénic ions in the presence of NBI.

![Figure 3: Observation of Alfvén cascades driven by NBI heating](image)

4. Conclusions

When used in the interferometry regime, an O-mode multi-channel reflectometer diagnostic allows the measurement of the Alfvén Cascades on JET with high frequency and time resolution much clearer than from any other diagnostic, as for instance the magnetic pickup coils. However the Alfvén Cascades cannot be localised with this technique. In the next JET experimental campaigns (starting in November 2005), it is planned to complement these results with measurements in the reflectometry regime from the X-mode correlation reflectometer diagnostic using new low attenuation transmission lines.

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