§6. Detection of High k Turbulence Using 2D Phase Contrast Imaging on LHD

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Transport in high temperature plasmas is often dominated by “anomalous” processes, thought to be due to the presence of turbulence at the ion and electron gyro-scale. Though much attention has been given to ion gyro scale instabilities, recent interest has been directed towards smaller scale instabilities, in particular the so-called electron-temperature gradient (ETG) mode. The challenge from a diagnostic point of view is to improve the sensitivity to smaller amplitude, smaller wavelength structures. The CO2 laser phase contrast imaging (PCI) system on LHD [1], which has up to now has been routinely used to diagnose low k turbulence (peak ~ 3cm^{-1}) was specially configured in some recent experiments to improve sensitivity to high k turbulence (k<30cm^{-1}). In this diagnostic, laser radiation scattering off fluctuations at a particular point in the plasma (referred to as the object plane) is imaged onto a detector array. For high k components, the depth of focus can be as small as a quarter of the minor radius. Therefore, if the object plane is shifted due to tolerances in the optical system, then the high k measurement may be strongly attenuated. To a simple approximation, for wave-like structures, the amplitude response *s* varies periodically with distance *L* between the object plane and the wave, known as the Talbot effect: $s=\cos(2\pi L/L_T)$, where the Talbot length L_T decreases with the wavelength of the fluctuation. This effect was used to calibrate the position of the object plane relative to the plasma by placing an ultrasonic loudspeaker adjacent to the beam at a known distance from the plasma as shown in Fig 1. As the ultrasound frequency is increased, the wavelength decreases thereby modifying the sensitivity from a maximum to a minimum and back to a local maximum according to the Talbot formula above. The precise frequency at which the minimum occurs (here f=104kHz) confirms (by comparison with calculation) that the object plane in this case is on the mid-plane of the machine (Z=0). By moving the imaging optics using a motor-driven roof mirror system, the object plane can be adjusted above or below the midplane.

Plasma fluctuation signals were measured at a range of different locations, from the midplane, where the normalized flux label ρ is 0.3 out towards the upper and lower edges of the plasma, and over a range of plasma discharge conditions. The fluctuation k spectra for two representative cases, during the ECH breakdown phase of a discharge, and during the NBI heated flat top of a (different) discharge are plotted in Fig. (2). The log-log plot emphasises the power law scaling of the spectrum. The instrument has a lower cutoff limit of k~2cm^{-1}, and necessarily causes the spectrum to fall away at low values of k. Also a roll-off on the high k side can be seen and there is a particular peak in each k spectrum. During the ECH breakdown phase, the peak is located around k=6cm^{-1} while during the NBI flat-top phase, the peak is located around k=4cm^{-1}. The slope of each curve for k above the peak is similar, indicating the spectrum shape is the same. The power as a function of k flattens out during the NBI heated phase for k>12cm^{-1} because the high k signal here is weak relative to leakage from low k. The significant and dramatic increase in higher k fluctuation power during the ECH phase may be because of strong electron temperature gradients induced during breakdown, and the absence of low k ion temperature gradient driven turbulence due to low ion temperature. The ultrasound test demonstrates that the diagnostic is correctly configured to measure high k turbulence and presence of ETG relevant high k turbulence during the ECH breakdown phase confirms its measurement capability. Therefore, we may conclude that the ETG-relevant turbulence is much weaker in the NBI phase. This may be because the normalized electron temperature gradient scale is comparatively weaker.

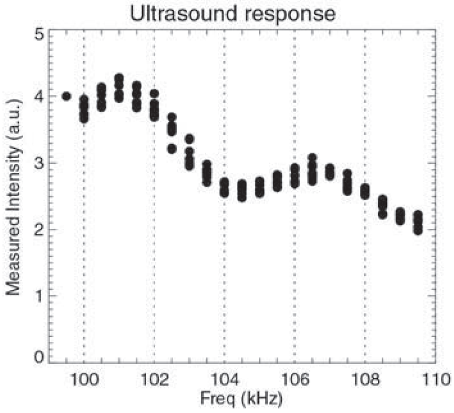

Figure 1: PCI response to ultrasonic frequency sweep showing modulation due to variation of Talbot length with sound wavelength (dependent on frequency)

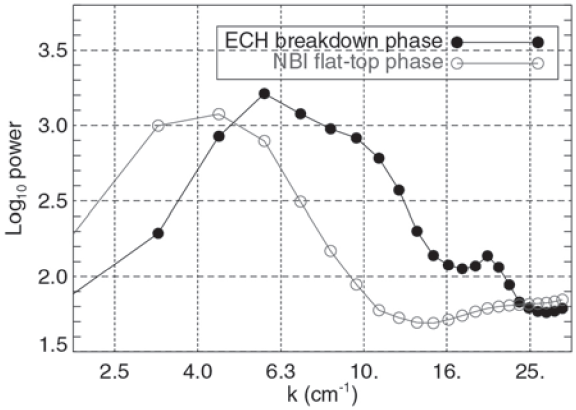

Figure 2: k spectra of turbulence during ECH breakdown phase at r=0.3 (filled symbols) and NBI flat top phase at r=1.0 (solid symbols)

[1] A. Sanin *et al.* Rev. Sci. Instrum. 75, 3439 (2004)