§3. 2D-Phase Contrast Imaging of Turbulence Structure on LHD

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Recently a 2D modification of the phase contrast interferometry (PCI) was advanced on LHD [1]. The 2-D PCI offers new possibilities for temporally resolved measurements of the frequency, wavenumber spectrum and its spatial distributions of turbulent fluctuations. The idea of the modification lies in two-dimensional structure of electrostatic turbulence where transverse correlation lengths are much shorter than longitudinal ones. Such turbulence can be thought of as a random set of long filaments orientated along the magnetic field. Due to magnetic shear, the degree of field-line twist is different at different locations along the viewing line within plasma. The top view of fluctuation associated with some locations looks like a ladder whose bars are orientated strictly along the magnetic field. Provided that focal depth of the PCI is larger than plasma size, the image of density fluctuations appears uniformly line-integrated and constitutes a pile of differently directed ladders. Analysis of elementary pictures from the line-of-sight integrated image can be performed using 2-D-spatial Fourier transform. Then Cartesian coordinates of 2-D Fourier transform are converted to polar ones so polar angles arc matched one-to-one with radial locations of fluctuations and polar radii with wavenumbers of fluctuations respectively. This technique in combination with 2-D multichannel detector array yields radial distribution of plasma density fluctuations with high temporal resolution determined by sampling rate and detector bandwidth. Temporal resolution offers new possibilities relative to earlier use of magnetic shear by 1-D methods [2, 3], which can produce radial distribution only on shot-by-shot basis. LHD has the additional benefit for improvement of the longitudinal resolution due to large magnetic shear: the magnetic field line direction projected perpendicular to the line of sight varies from -30 to 40 degrees as the probe beam travels from the plasma bottom to the plasma top within the last closed flux surface. The employed detector array is a 8 by 6 element matrix of photoconductors. Its image in the plasma has size of 6 by 17.5 mm².

Figure 1(a) shows three successive frames recorded by the array with 1MHz sampling rate in plasma shot with parameters: electron density \( n_e = 1.710^{19} \text{m}^{-3} \), electron temperature \( T_e = 2 \text{keV} \), toroidal magnetic field strength \( B_t = 1.49 \text{T} \). To visualize motion of plasma density fluctuations the raw image is digitally split into two parts with negative (b) and positive (c) tilting angle associated with lower and upper halves of the plasma cross-section. Extended along the magnetic field moving objects are clearly seen in figures (b) and (c). Their movement corresponds to plasma rotation in the electron diamagnetic direction with instantaneous velocity \( V_{E}^D = 2 \text{km/s} \). Fluctuations are localized near \( \rho = 0.9 \) and the width of the peak is larger than the instrumental width determined by calibration with ultra sound waves in air. Not only simple propagation, but also intermittent and burst-like signals are observed as well. The intermittent and burst behaviours will be the target of future study.