§6. Observation of Plasma Fluctuations by using the Omode Microwave Imaging Reflectometry (O-MIR) in LHD

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It is considered that thermal conduction and particle diffusion are governed by fluctuations. Visualization of local electron density fluctuations will be very useful to study the physics of confinement and instabilities in fusion plasma. Since the plasma reflects the O-mode microwave at the plasma frequency, the fluctuation can be visualized by using the microwave imaging reflectometry (MIR). In the Large Helical Device (LHD), MIR has been intensively developed [1]. Recently, the O-mode MIR has been developed in LHD. The frequency is 26 – 34 GHz. This corresponds to the electron density of 0.8 – 1.5 × 10^{19} m^{-3}, which is typical in the internal transport barrier (ITB) in LHD. The plasma is illuminated by the Gaussian beam with four frequencies, which correspond to four radial positions. The reflection layer is estimated from the electron density profile which is obtained by the Thomson scattering. The imaging optics make a plasma image onto the newly developed 2D (8×8) Horn-antenna Millimeter-wave Imaging Device (HMID). In HMID, the signal wave that is accumulated by the horn antenna is transduced to the micro-strip line by using the finline transducer. By the double balanced mixer, the signal wave is mixed with the local wave, which is delivered by cables. Thus the O-MIR optics are extremely simplified and the local wave power can be optimized. Each intermediate frequency (IF) signal is amplified by a narrow band amplifier, and the power and phase are digitized with the sampling rate of 1 MHz.

Since the signal-to-noise ratio is significantly improved, the wave number of the fluctuation can be obtained by the two point correlation analysis, as follows:

$$k_{ij} = \frac{1}{d_{ij}} \tan^{-1}\left(\frac{\operatorname{Im} S_{ij}(\omega)}{\operatorname{Re} S_{ij}(\omega)}\right) \qquad (1)$$

Here Sij is the cross-power spectrum between two points *i* and *j*, as

$$S_{ij}(\omega) = \left\langle F_i^*(\omega) F_j(\omega) \right\rangle$$

$F_i(\omega)$ is the Fourier transform of the MIR power signal $x_i(t)$ at the point *i*, d_{ij} is the distance between two points *i* and *j*, ω is the angular frequency, and k_{ij} is the wave number of the plasma wave propagating from the points *i* and the point *j*.

In the case of L-mode, the ω-k curve is not clear while the power of the signal spectrum is hundreds of times greater than the noise. In the case of ITB, the signal power is much lower, but the group velocity can be obtained from the ω-k curve. The group velocity of the wave is

$$v_g = \frac{\partial \omega}{\partial k} \qquad (2)$$

An example of the distribution of the ω-k curve for the poloidal wave number is shown in Fig. 1. Direction of poloidal group velocity is sometimes inversed. The velocity direction is turned in the frequency region and also in both poloidal and toroidal directions. Thus the flow patterns make cells.

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1) Nagayama, Y. et al: Rev. Sci. Instrum. **83**, 10E305 (2012).
2) Kuwahara, D. et al: Rev. Sci. Instrum. **85**, 11D805 (2014).

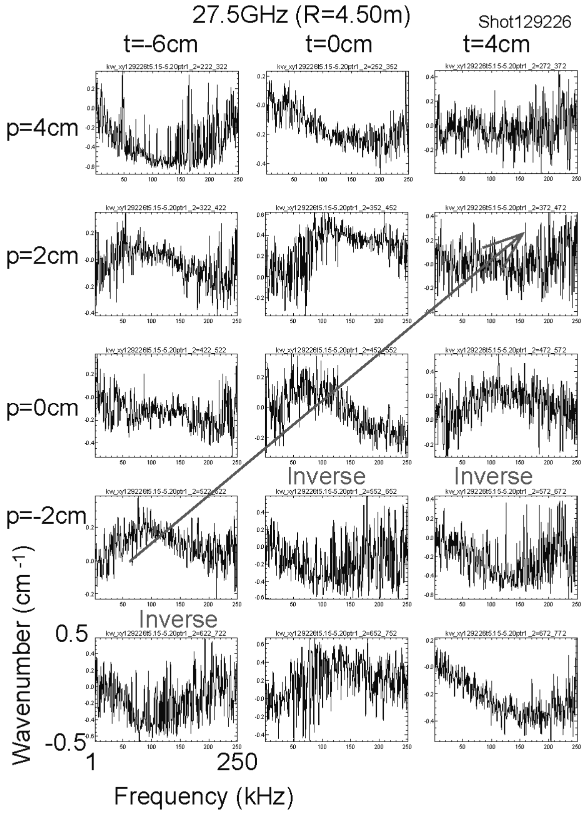

Fig. 1 Typical example of the distribution of the poloidal wave number *k* as a function of ω.