# §1. Discovery of Zonal Magnetic Field in CHS

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The heavy ion beam probe (HIBP) measurements in CHS discovered the existence of zonal flows for the first in magnetically confined plasmas [1]. In CHS the method of magnetic field fluctuation using the HIBPs has been developed and was carried out in order to confirm the existence of zonal magnetic field, which has been expected in several theories. The trials were performed at the radial position of $r_{obs}$~12 cm (or ρ~ 0.6), where the maximum signal-to-noise ratio was obtained for the HIBPs in the ECR-heated plasmas.

Figure 1 shows the measured spectrum of the magnetic field fluctuation, together with coherence between two toroidal locations. The dashed line is the estimated maximum (or the upper boundary) of contamination due to the electric field fluctuation. The coherence is quite high (~0.7) in the frequency regime lower than 1 kHz,. Note that a trajectory calculation shows that the horizontal beam movement reflects the poloidal magnetic field in this series of measurement. Similarly to zonal flows, the magnetic field fluctuations of this frequency are identical at two toroidal positions if they are on the same magnetic field surface in this low frequency range. On the other hand, two signals on slightly different magnetic flux surfaces coherently change with a finite constant phase. Consequently, the fluctuation should have symmetric structure with a finite radial wavelength [], thus, the magnetic field fluctuation should be the zonal magnetic field.

A constant phase relation between the signals from two different radial positions allows us to estimate the spatio-temporal characteristics of the zonal magnetic field in the radial direction by evaluating the correlation function.. Figure 2 shows the cross-correlation obtained by altering an observed position r', shot by shot with fixing the other at r(=12 cm). Figure 2 illustrates the spatial structure of three times at $\Delta t = 0$, 1 and 2 ms. The correlation diagrams show a quasi-sinusoidal structure in the radial direction with a characteristic radial wavelength of $\lambda_r$~1.5 cm (zonal structure), while the memory of the structure is lost in ~ 2 ms.

The wavelet bicoherence analysis was applied to prove the causal relationship between the zonal magnetic field and turbulence, and succeeded in verifying the existence of the coupling, suggesting that the modulational instabilities should play an important role in the field generation, as is similar to the case of zonal flows.

Finally, this is the discovery of the zonal magnetic field, and the experimental proof which demonstrates the dynamo hypothesis, i.e., the turbulence can really generate the global magnetic field structure

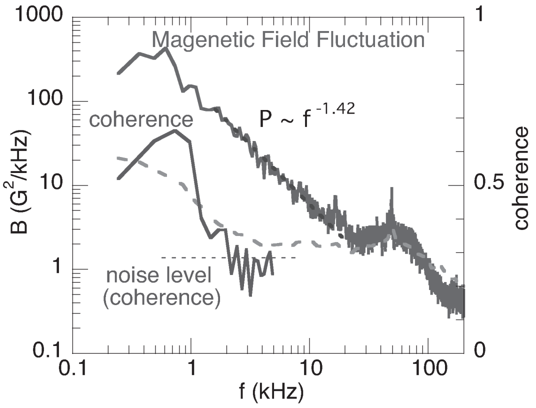

Fig. 1. Magnetic field fluctuation spectrumand coherence between the magnetic field at two toroidal locations. The spectrum is calculated for the stationary period of ~50 ms for the discharge duration of ~100ms with frequency resolution of 0.24 kHz and the Nyquist frequency of 250 kHz.

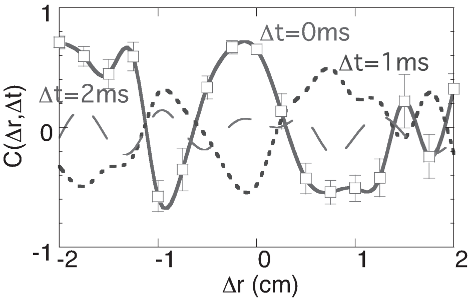

Fig. 2. Correlation functions with three different time delays; Δt=0,1 and 2 ms. The correlation diagrams show radial structure of zonal field, which has a quasi-sinusoidal radial structure with a characteristic radial wavelength ~1 cm).

[1] A, Fujisawa et al., Phys. Rev. Lett. **93** 165002 (2004)

[2] A, Fujisawa et al., Phys. Rev. Lett. **98** 165001 (2007).

[3]A. Fujisawa et al., Plasma Phys. Control. Fusion **49** 845 (2007).