# CHARACTERISTICS OF ELECTROMAGNETIC TURBULENCE ON KTX EXPERIMENT DEVICE

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**Abstract**

Electrostatic turbulence is the main constrain of confinement improvement on low "β" toroidal magnetic confinement devices. With the development of high "β" operation scenario, electromagnetic turbulence is expected to become important for development of resistive tearing mode and resistive wall mode. The characteristics of electromagnetic turbulence on KTX are studied in low current tokamak and in reversed field pinch plasma operations. Electron density fluctuations in the core and edge area are measured based on forward scattering signal collection with interferometer system. The edge electric and magnetic field fluctuations are measured using movable multi-functional probe arrays. The spectral characteristics of the electromagnetic turbulence are present in our research.

## 1. INTRODUCTION

Two kinds of fluctuations are critical in magnetic confinement plasma, magnetic and electrostatic. Both fluctuations cause transport and make the confinement worse in most cases. One of the most significant experiment research results on tokamak is the realization of H mode operation in recent decades [1]. With the increase of input power, spontaneous formation of transport barrier arise with the decrease of edge transport, and the confinement is largely improved. Existing experiment results shows that the suppression of electrostatic turbulence by E×B flow is an important physical mechanism. For example, the variation of radial electric field is measured during transition of L mode to H mode on JFT-2M [2] tokamak. The biased electrode experiment also prove that flow shear induced by radial electric field reduce the transport level directly. Also, experiment on Extrap-T2R reversed field pinch shows that turbulence Reynolds stress may play an important role [3]. Those evidences indicate that the safe organization mechanism behind the interaction of turbulence with transport may be similar in different magnetic configurations.

Magnetic fluctuation is another important parameter in the confinement scaling laws. The confinement tend to decrease with the increase of β, which is not expected in the theory mode of pure electrostatic turbulence. Also, magnetic fluctuation is very important during disruption and sawtooth behavior of tokamak plasma [4]. Though wide spectrum of magnetic fluctuation were reported on small tokamak [5], magnetic turbulence is very hard to be measured under advanced tokamak operation mode with strong toroidal magnetic field. Recently, experiment on TEXTOR [6] show that magnetic fluctuation amplitude tend to increase in the ramping down period of plasma current, the amplitude is affected by toroidal magnetic field and electron density, and can also effect the suppression of runaway electron. Wide spectrum mic-tearing mode proposed by Marie Firpo gave reasonable explanation for randomness of magnetic field lines [7]. With the increase of β in future advanced tokamak devices, the amplitude of magnetic fluctuation will also increase, the role of magnetic turbulence may became important.

In the reversed field pinch, magnetic fluctuations have been identified as current driven modes with resonant surfaces inside the reversed surface. The nature of generation and sustainment of the mean toroidal magnetic is also identified as the nonlinear dynamics of those modes, which is called RFP dynamo. Those mode is believed to cause strong transport and poor confinement of the plasma. It is reported that high frequency electrostatic fluctuation mainly cause the particle loss in the edge of the RFP plasma [8], and give only less than 15% contribution of energy loss. The dominant energy loss channel is magnetic fluctuation. It is reported that there may be nonlinear interaction between internal low frequency tearing modes and edge high frequency electrostatic turbulence [9]. Also, anisotropic magnetic turbulence with high frequency is also reported on MST reversed field pinch [10]. The relationship between the magnetic and electrostatic fluctuations can be important to help understand the mechanism behind abnormal transport, which can't be explained by single kind of fluctuations.

In the paper we present experimental observations in low current tokamak plasma and RFP plasma on KTX, which shows the characteristic of both magnetic fluctuations and electrostatic fluctuations. The results also shows the difference in two kinds of toroidal magnetic configurations in low frequency and high frequency region.

## 2. EXPERIMENT ARRANGEMENT

KTX is a middle size reversed field pinch device (The major radius R=1.4m, and the minor radius r=0.4m), and now can be operated in low current tokamak mode, with plasma current around 40kA, and time duration over 20ms, reversed field pinch plasma can also be achieved on KTX with edge toroidal field reversed for about 2ms[11]. In the experiment, a 4-pin Langmuir probe and a 9-pin Langmuir probe at different toroidal position are used to measure the edge floating potential and plasma potential. As shown in Fig. 1(a). A rake like probe is inserted from the “O” horizontal window, and the tips of the probe array are arranged at the same radial position in the poloidal direction of cross section of the vacuum vessel. The distance in poloidal direction $\Delta_\theta$ is 6mm. A 4-pin Langmuir probe is set 30 degrees away in toroidal direction at the “M” horizontal window. Both probes can be set at the same radial position of 0.36m from the center axis of the inside vacuum vessel. The middle two tips at ‘M’ window is at the same poloidal position with the bottom tip of the rake like probe at ‘O’ window. This arrangement allows for correlation analysis of electrostatic fluctuations in the poloidal direction and in the toroidal direction.

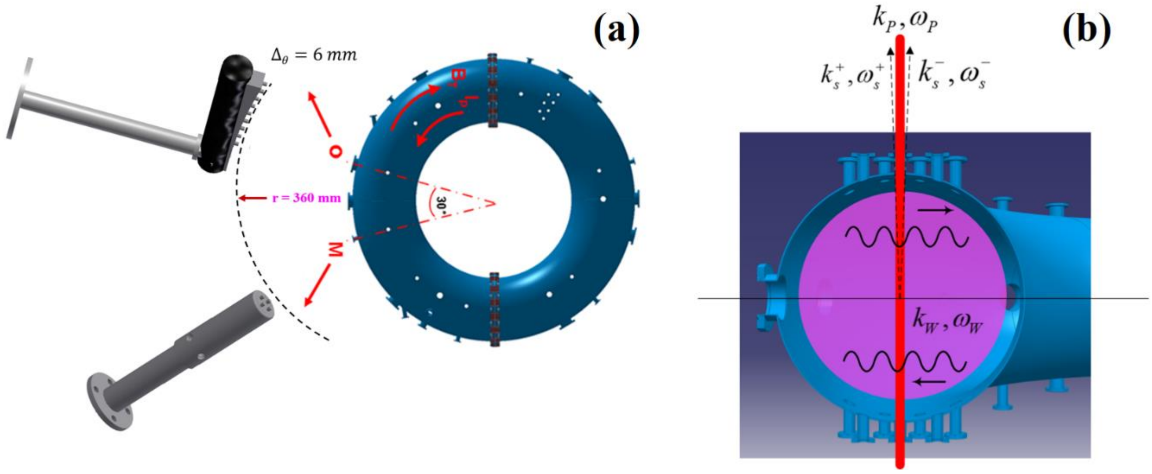


*FIG. 1. (a) Diagram of edge probes arrangement on KTX vacuum vessel windows, (b) Diagram of the forward scattering signal collection on KTX*

The electron density fluctuation is measured from the collection of forward scattering signal of the center chord interferometer system. The chord averaged electron density waveform can be achieved simultaneously. As shown in Fig. 1(b), a 650 GHz probing beam go vertically through the center chord of vacuum vessel with incident wave vector $k_P$ and frequency $\omega_P$. The electron coherent structures with wave vector $k_W$ and frequency $\omega_W$, rotating along the poloidal direction in the small cross-section of KTX, will encounter with the probing beam twice, which will generate two forward scattering beams almost symmetrically distributed around the injection beam. The transmission aperture of the vacuum ports is 35 mm. Given the geometry limitation of the device and optical arrangement, the forwarding scattering signal with angle less than $2^o$ can be collected by the plasma mixer. The characteristic length of scattering is about 0.2cm, the maximum value of measured $k_W$ is about 5 $cm^{-1}$ and the resolution of the density fluctuation wave vector is ~$2cm^{-1}$.

## 3. EXPERIMENTAL RESULTS

### 3.1. Edge floating potential fluctuation

The energy spectrum of edge floating potential fluctuation at different radial positions for high current low q discharge and low current tokamak discharge are shown in Fig. 2. The exponentials in scaling-law at different radial positions indicate different turbulence development states. We can see that fluctuation up to 200 kHz exist in both discharges, and for low current tokamak discharge, there is obvious peak around 10 kHz. At a deeper radial position, the low frequency peak tend to broaden, which is internal tearing mode like fluctuations.

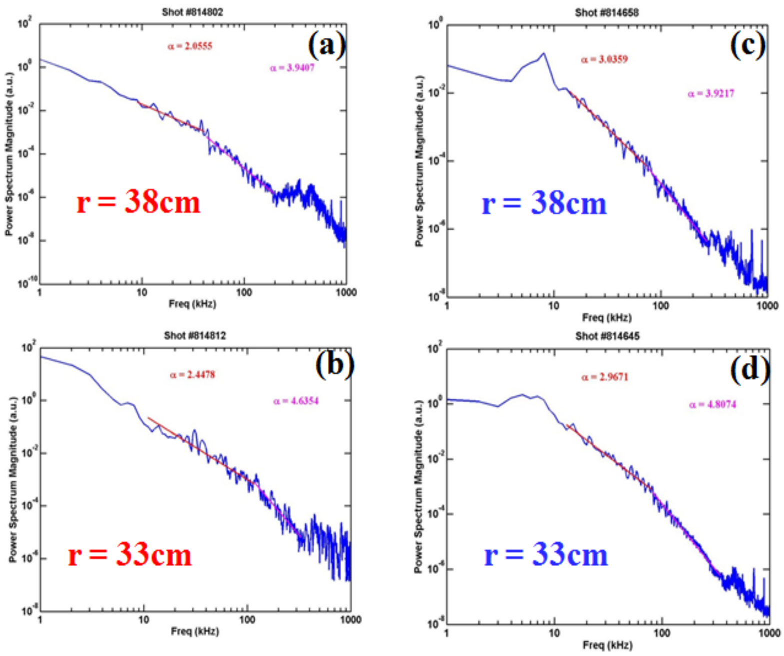


*FIG. 2. Energy spectra of floating potential in low q high current discharge (a) at radial position r=38, (b) at radial position r=33, and in low current tokamak discharge (c) at radial position r=38, (d) at radial position r=33*

The wavenumber-frequency structure for low-q large current discharges and low current tokamak discharges are measured by classical two-point technique as shown in Fig. 3. Similar with the energy spectrum, fluctuations with frequency up to 200 kHz, and spatial spectrum up to 5cm$^{-1}$ can be recognized. In both discharges, the fluctuation spread in outward radial direction. The turbulence spectra in low-q discharges are wider than that in the low current tokamak discharge. And the center concentration at poloidal wavenumber spectrum for low current tokamak discharge indicates larger poloidal spatial structure.

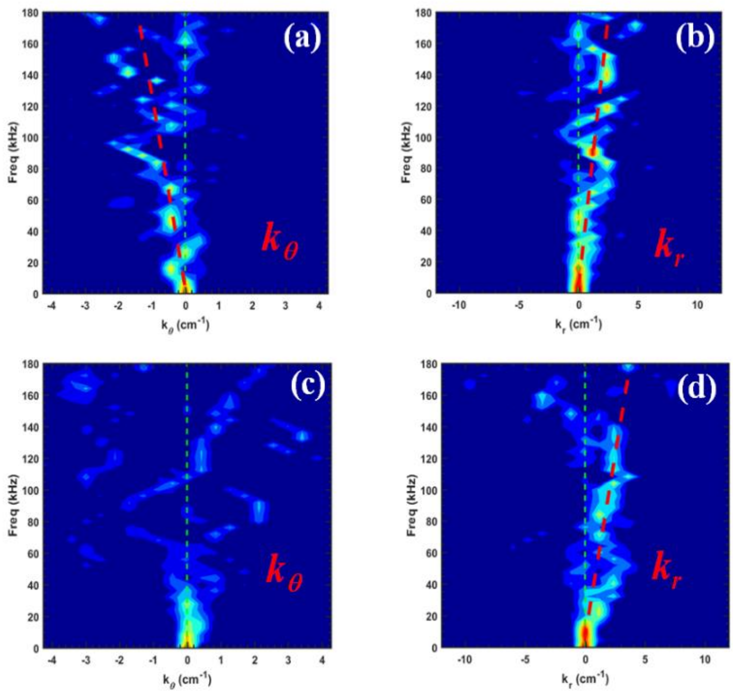

*FIG. 3. Wavenumber-frequency structure for low-q large current discharge (a) in electron diamagnetic direction, (b) in outward direction and for low current tokamak discharges (c) with center concentration, (d) in outward direction*

Coherence analysis results in poloidal direction and toroidal direction are shown in Fig. 4. The left row shows the correlation between two floating potential signals from tips of ‘O’ window probe as described in section 2, and the right row shows the correlation between one tip of ‘O’ window probe and one tip of ‘M’ window probe. One can see that the highest coherence power density is of low frequency around 2 kHz, which may be comparable to the frequency of the kink modes. A notable second peak appears around 20 kHz, which may be comparable to the frequency of the internal tearing modes. From the phase difference the mode number can be measured for the mode with frequency around 20kHz, which is m=6, and n=1.

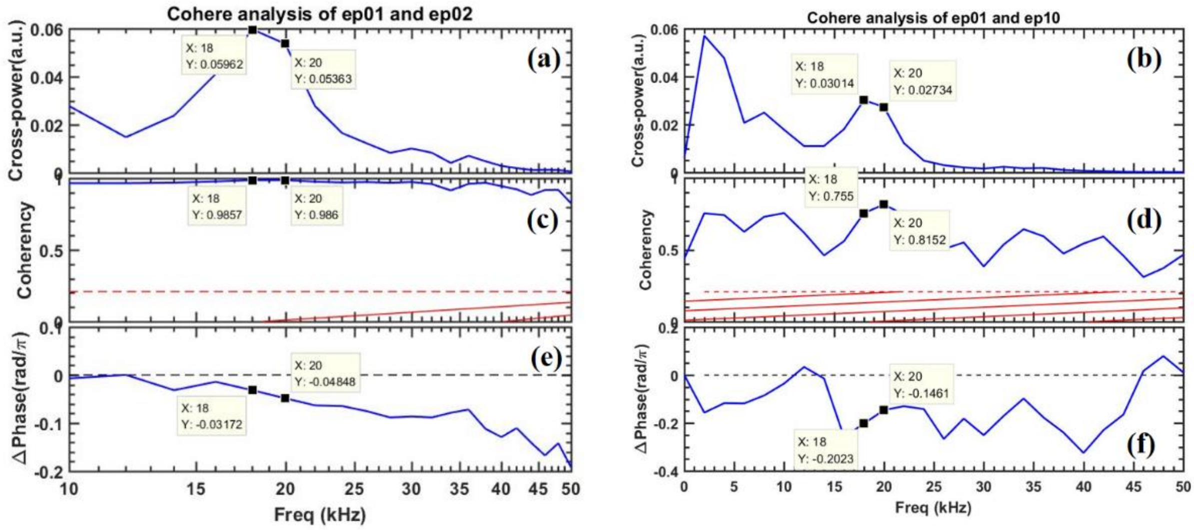


*FIG. 4. In low current tokamak discharges, cross power of floating potential fluctuation (a) between tip ep01 and tip ep02 of ‘O’ window probe in polodial direction, (b) between tip ep01 of ‘O’ window probe and tip ep02 of ‘M’ window probe in toroidal direction, coherency of floating potential fluctuation (c) between tip ep01 and tip ep02 of ‘O’ window probe in polodial direction, (d) between tip ep01 of ‘O’ window probe and tip ep02 of ‘M’ window probe in toroidal direction, phase difference (e) between tip ep01 and tip ep02 of ‘O’ window probe in polodial direction, (f) between tip ep01 of ‘O’ window probe and tip ep02 of ‘M’ window probe in toroidal direction*

Fig. 5 shows the correlation analysis between floating potential of one tip from ‘O’ window probe and one Bp mirror probe at the edge of plasma in low current tokamak discharge. It can be seen that there are strong correlation at frequency around 20 kHz and at frquency around 2 kHz, which is similar with the phenomenon in Fig. 4(b).

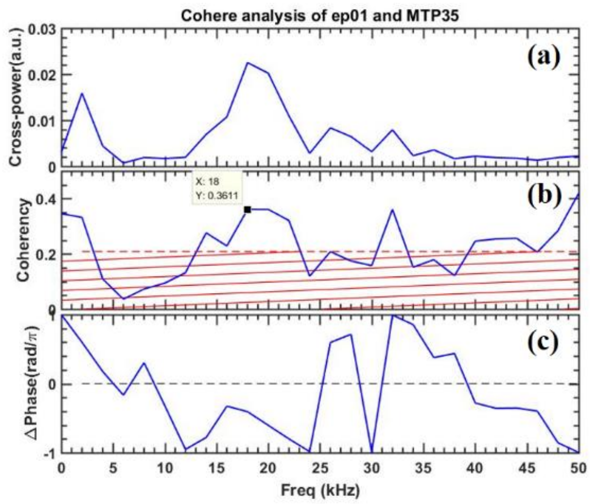

*FIG. 5. In low current tokamak discharge, (a) corss power, (b) coherency and (c) phase difference between floating potential fluctuation and edge Bp flucutation,*

### 3.2. Density fluctuation

As shown in Fig. 6, the density fluctuation frequency spectrum from forward scattering signal is compared with chord averaged electron density frequency spectrum. A low frequency MHD mode between around 2kHz and 4kHz is shown from both results, however the forward scattering signal show more detail in the high frequency range above 10kHz for its higher spatial resolution.

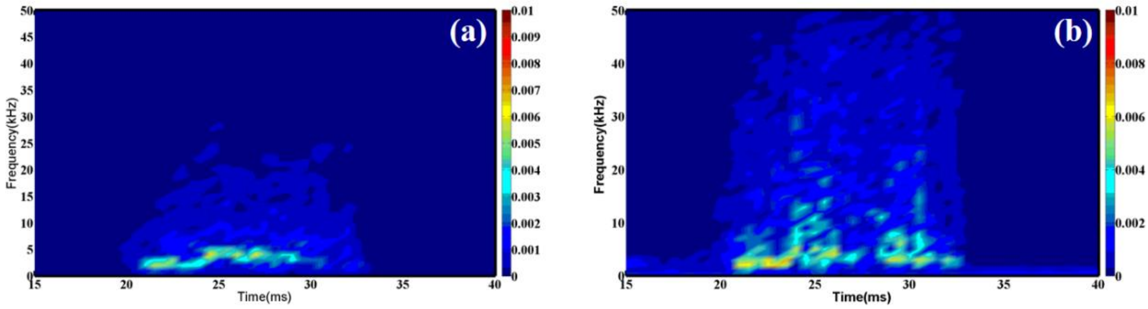


*FIG. 6. Frequency spectrum of (a) center chord averaged electron density, (b) electron density fluctuation by forward scattering in low current tokamak discharge*

The spectrum of poloidal magnetic field fluctuation is compared with electron density fluctuation by forward scattering as shown in Fig. 7. There is clearly a mode with frequency around 20 kHz from Bp fluctuation spectrum, while the density fluctuation show a wider frequency range up to around 50 kHz. Compared with electron density fluctuation in low current tokamak discharge, there seems to be more internal tearing modes with wider fluctuation frequency range.

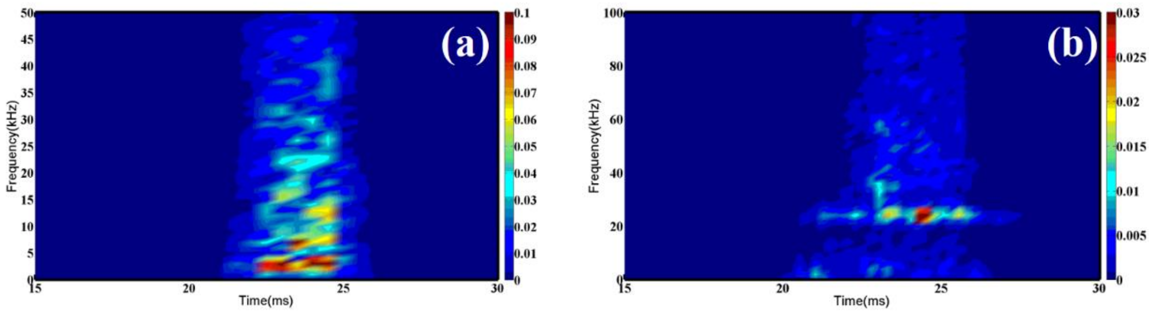


*FIG. 7. Frequency spectrum of (a) electron density fluctuation by forward scattering , (b) Bp edge mirrnov probe in reversed field pinch discharge*

## 4. SUMMARY

The possible correlation between the edge electrostatic fluctuation and the MHD mode is shown from the experiment results on KTX in both low current tokamak discharge and RFP discharge. The low frequency electrostatic modes, up to 20 kHz, showing the same frequency and similar mode spectra as those of MHD modes, which may be global kink or tearing modes, were detected on the edge electrostatic potential fluctuations and the center chord electron density fluctuations. Compared with low current tokamak discharges, the fluctuation tend to show wider spectrum in RFP discharges.

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