Experimental Investigation of the Magnetic Fluctuations in a Toroidal Plasma

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This paper presents experimental results on the magnetic field fluctuations in the KT-5C tokamak plasma, including magnetic field fluctuation frequency spectra and the radial profile of the fluctuation amplitudes. These results show that the low frequency components are dominant for the magnetic field fluctuation signals, and that the magnetic field fluctuation levels decrease towards the edge of the plasma. A remarkable influence of the gas puffing level on the amplitude of the magnetic field fluctuations was observed.

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I. Introduction

It has long been known that the rate at which energy leaves the tokamak plasma is much faster than that predicted by classical collisional transport theory calculated for the tokamak magnetic field geometry (neoclassical transport theory). The anomalous transport has generally been attributed to microscopic plasma turbulence, i.e. turbulence with spatial scales much smaller than the plasma radius. Fluctuations in the electric and magnetic fields in a tokamak cause fluctuations in the particle's velocities and positions and thus can lead to transport [1]. Much effort has gone into determining how large an effect the microturbulence has on the global confinement. Magnetic fluctuations have been measured in many tokamaks [2–6]. There is much similarity in the results of these fluctuation measurements, and thus it appears that the nature of the microturbulence in tokamaks is rather universal. The general features of the magnetic fluctuations could be summarised as flows: broadband magnetic field fluctuations have been seen in every machine in which measurements were done; the correlation lengths of the magnetic field fluctuations in tokamaks show that $L_{\parallel} \gg L_{\theta} \simeq L_r$; the magnetic field fluctuations in the $r-\theta$ plane are nearly isotropic and much larger than the toroidal magnetic field fluctuations. However, measurements of microturbulence in tokamak plasmas are far from complete in any sense.

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II. Experimental Setup

The magnetic fluctuation experiments were conducted in the KT-5C tokamak plasma. The experimental setup is shown in Figure 1. The KT-5C tokamak is a small toroidal machine with $R = 32.5$ cm, $a = 12.5$ cm, $I_P \leq 20$ kA, $B_t \leq 0.6$ T, $T_{e0} \sim 100$ eV, $n_{e0} \sim (1-2) \times 10^{19}\ \mathrm{m}^{-3}$. The relatively cool, low-density plasma permitted the use of magnetic probes near the center of the various discharges so that interior measurements could be made. The magnetic field fluctuation signals were obtained using magnetic pickup coils. The magnetic probes consist of five calibrated coils distributed along an isolator bar with 0.2 cm diameter and arranged to measure the poloidal magnetic field fluctuations at five different points in the plasma. The coils are 1.1 mm long, about 1.6 mm in diameter and have 11 turns of 0.1 mm wire. The coil-to-coil separation along the radial direction is 1.5 cm from center to center. The probe assembly, with a 0.2 cm diameter stainless steel tube for shielding, is placed inside a quartz tube for insertion into the plasma. We also have constructed a probe assembly to measure the fluctuations of the radial magnetic field. The absolute calibration of all these magnetic probes was done utilizing Helmholtz coils. Due to the small signal level from the magnetic pickup coils the output from the probes was amplified and filtered. The filters used were $n = 4$ elliptic bandpass filters. It was found that the probe disturbance of the plasma is negligible during the discharges even when the probes were inserted well inside of the plasma, until $r = 4.5$ cm.

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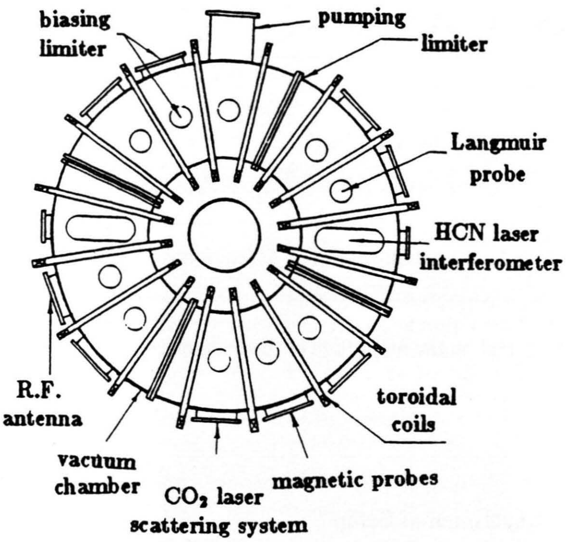

Fig. 1. Experimental setup.

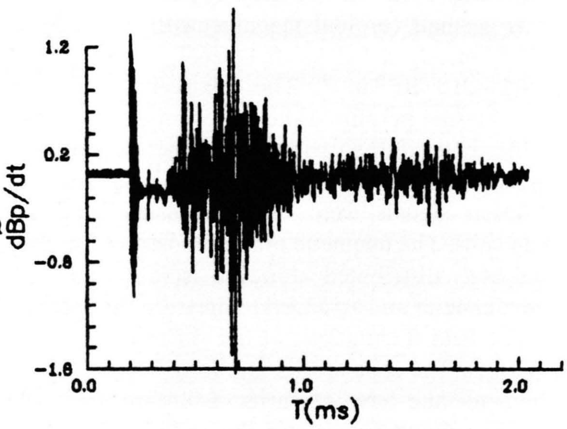

Fig. 2. Raw data of magnetic field fluctuations ($d\tilde{b}/dt$).

III. Data Analysis

Magnetic field fluctuation signals from the pick-up coils were digitized at a frequency of 4 MHz. The data were processed using standard spectral analysis. For a fluctuating magnetic field $B(t)$ over a time period T, which involves many frequency components, the amplitude is best expressed as a root-mean-square (rms) value given by

$$\tilde{B} \equiv \left(\frac{1}{T}\int_0^T B^2(t)\,dt\right)^{1/2}, \tag{1}$$

However, it should be noted that the signal from a magnetic coil is not $B(t)$ but rather $\dot{B}(t) = dB(t)/dt$. Rather than integrate the signal and proceed as above, we used Fourier analysis coupled with a frequency calibration of the entire probe-amplifier-transmission system. Let $\dot{B}(t)$ be a finite time record of a probe signal in volts over a period T. If $\dot{B}(f)$ is the Fourier Transform of $\dot{B}(t)$ and $C(f)$ is the calibration of the probe system in gauss/volt, then the rms fluctuation amplitude in gauss is given by [7]

$$\tilde{B} = \left(\int df[C(f)]^2 \frac{1}{T}\langle|\dot{B}(f)|^2\rangle\right)^{1/2}, \tag{2}$$

where $\langle\ \rangle$ indicates an ensemble average.

The amplitude spectrum $\tilde{b}(f)$ in gauss/(frequency)$^{1/2}$ is given by

$$\tilde{b}(f) = C(f)\left[\frac{1}{NT}\langle|\dot{B}(f)|^2\rangle\right]^{1/2}, \tag{3}$$

where N is an artifact of the discrete Fourier transform, which has the discrete analogue

$$\tilde{b}_n = C_n\left[\frac{1}{NT}\langle|\dot{B}_n|^2\rangle\right]^{1/2}. \tag{4}$$

IV. Results and Discussion

Every value we used in the following spectral analysis is the averaged value over three successive shots. In this paper, only the magnetic field fluctuation signals corresponding to the flat parts of the plasma current (from the time 1.0 ms to 1.5 ms) were chosen for the analysis because the plamsas were relatively quiet during this period. The raw data of the magnetic field fluctuations are shown in Fig. 2, which was restored from the digiter records.

The $\tilde{B}_p$ frequency spectra obtained through Fast Fourier Transform for two different positions, at $r = 4.4$ cm and at $r = 11.1$ cm, are shown in Figure 3. One can see from this diagram that broadband magnetic field fluctuations exist in the KT-5C tokamak plasma just like in many other tokamaks. The level of the magnetic field fluctuations in the range of low frequencies is much higher than that in the range of high frequencies. Fig. 3 also shows that the amplitude of the magnetic field fluctuations at frequencies below 100 kHz is two orders of magnetic higher than that at frequencies above 800 kHz, which implies that the low frequency components are dominant for the magnetic

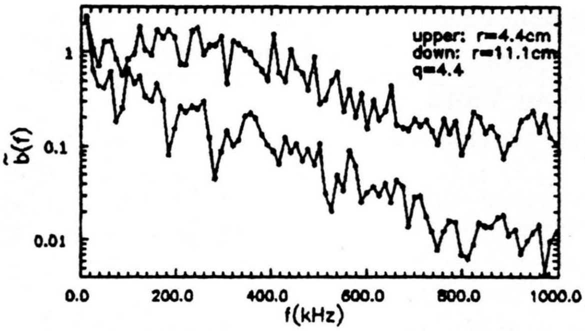

Fig. 3. Frequency spectra in gauss/(kHz)$^{1/2}$ of the poloidal component of magnetic field fluctuations at $r = 4.4$ cm and $r = 11.1$ cm, $q_a = 4.4$.

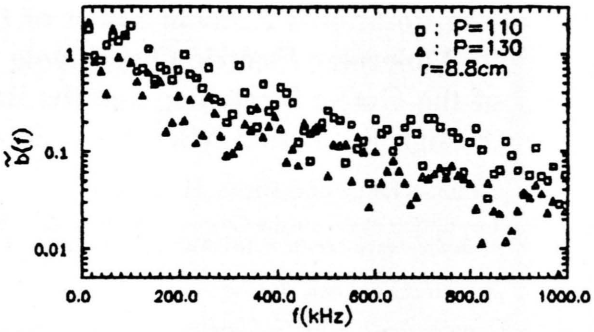

Fig. 5. The influence of gas puffing on the amplitude of magnetic field fluctuations. Squares: 110, triangles: 130.

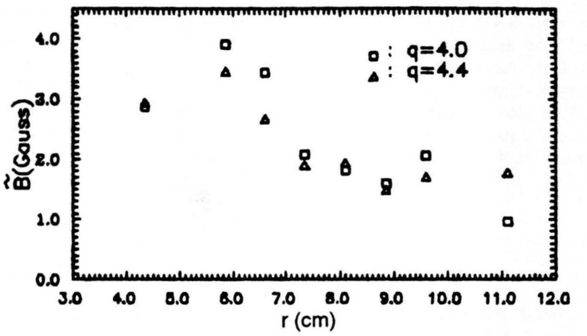

Fig. 4. Radial profiles of poloidal magnetic field fluctuation amplitudes for discharge of two different values of q_a. Squares: $q_a = 4.0$; triangles: $q_a = 4.4$.

field fluctuation signals. On the other hand, the amplitudes of the magnetic field fluctuations at $r = 4.4$ cm are much larger than those at $r = 11.1$ cm.

Radial profiles of poloidal magnetic field fluctuation amplitudes were investigated in our experiment. The experimental results of ther radial profiles for discharges of two values of q_a are shown in Fig. 4, where $\tilde{B}_p$ is the total amplitude over the frequency range 12–500 kHz. For a given value of the factor q_a, the magnetic field fluctuation level increases as the probe is inserted farther into the plasma. Obviously, this is contrary to what was observed in plasma density fluctuation measurements in many other tokamaks, where the level generally seems to increase towards the edge of ther plasma [8, 9]. In Fig. 4 one can also see that the amplitudes of the magnetic field fluctuations decrease slightly as the values of q_a increase.

A remarkable decrease of the amplitudes of magnetic field fluctuations was observed when the gas puffing level (hydrogen) increased in a reasonable range. The $\tilde{B}_p$ frequency spectra for two different gas puffing levels are shown in Fig. 5, where the two traces correspond to the gas puffing levels 110 (squares) and 130 (triangles). The numbers 110 and 130 are the gas puffing meter readings.

In conclusion, the experimental results show that broadband magnetic field fluctuations exist in the KT-5C tokamak plasma just like in many other tokamaks, in which the low frequency components are dominant for the magnetic field fluctuation signals. The radial profiles of the poloidal magnetic field fluctuations were obtained for different discharge conditions, which show that the magnetic field fluctuation levels decrease towards the edge of the plasma. Also a remarkable influence of the gas puffing level on the amplitude of the magnetic field fluctuations was observed.

Acknowledgement

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[1] P. C. Liewer, Nucl. Fusion **25,** 543 (1985).
[2] S. J. Zweben and R. J. Taylor, Nucl. Fusion **21,** 193 (1981).
[3] S. J. Zweben, P. C. Liewer, and R. W. Gould, J. Nucl. Mater **111 & 112,** 39 (1982).
[4] S. J. Levinson, B. Rogers, E. J. Rogers, and R. D. Bengtson, Bull. Amer. Phys. Soc. **30,** 1441 (1985).
[5] Y. J. Kim, K. W. Gentle, C. P. Ritz, T. L. Rhodes, and R. D. Bengtson, Nucl. Fusion **29,** 99 (1989).
[6] D. Graessle, S. C. Prager, and R. N. Dexter, Phys. Rev. Lett. **62,** 535 (1989).
[7] D. Graessle, S. C. Prager, and R. N. Dexter, Phys. Fluids **B 9,** 2626 (1989).
[8] E. Mazzucato, Phys. Rev. Lett. **48,** 1828 (1982).
[9] C. M. Surko and R. E. Slusher, Science **221,** 817 (1983).