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Measurement of Magnetic Field Fluctuations within Last Closed Flux Surface with Movable Magnetic Probe Array in the JIPP T-IIU Tokamak

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ABSTRACT

Poloidal and radial magnetic field fluctuations less than 100 kHz are measured with a newly developed movable magnetic probe array in the JIPP T-IIU tokamak. The probe array protected by a carbon/carbon - composite with 20% boron is inserted beyond the last closed flux surface (LCFS) up to $r/a \simeq 0.77$ without deleterious effect on ohmically and neutral beam heated plasmas. From the radial variation of the fluctuation amplitude just outside LCFS the poloidal mode number is estimated to be $m \leqq 4$ for low frequency coherent part ($f<30$kHz) and $m \sim 10$ for relatively high frequency incoherent one ($f>50$kHz)

Keywords: Tokamak plasma, Movable Magnetic Probe Array, Magnetic Fluctuations, Coherence, Poloidal Mode Number

INTRODUCTION

Correlation between plasma transport and turbulent fluctuations is one of the most important issues in recent researches of tokamak plasma confinement. So far a role of electrostatic fluctuations is paid much attention, for instance, particle and thermal diffusivities of the plasma core correlate well with density fluctuations[1] and those in the plasma edge of ohmically heated plasmas also correlate well with electrostatic fluctuations[2]. On the other hand, the JET group has reported global energy confinement time is increased with the decrease of incoherent magnetic fluctuations[3]. At the H-mode magnetic fluctuations as well as electrostatic fluctuations near the edge are clearly suppressed[4,5]. Magnetic fluctuations may play an important role in a plasma transport during auxiliary heating. Magnetic fluctuations are detected only with Mirnov coils outside LCFS[3], or in the plasma interior with a movable probe in low temperature, low density and short pulse tokamak plasmas[6]. We have developed a new type of movable magnetic probe array to study the role of magnetic fluctuations in plasma transport.

EXPERIMENTAL SET-UP AND RESULT

Figure 1 shows the movable magnetic probe array installed in the JIPP T-IIU tokamak [7] and its detailed structure. As shown in Fig.1, the stainless steel pipe is covered with a cap of carbon/carbon -composite with 20% Boron, to protect the pipe from plasma bombardment and to minimize impurity efflux from it. As shown in Fig.2, CII and H_α emissions remain unchanged, independent of the insertion of the probe up to $r/a \simeq 0.77$ (at the head of the carbon cap). The emission of OII line also remains unchanged.

The fluctuations less than 100kHz can be detected, although the amplitude is reduced by about 10dB at f=100kHz due to shielding effect of the stainless steel pipe. The resonance frequency of the magnetic probe is nearly 150kHz. The signal-to-noise ratio is more than 50 dB.

In JIPP T-IIU, we are studying the effects of edge magnetic field structure on plasma confinement by means of rapid ramp-up or ramp-down of the plasma current. In this paper, we discuss magnetic fluctuations detected with the movable probe in the current ramp-up discharge (Fig.2). Figure 3 shows power spectrum of the magnetic fluctuations when the head of the probe array is inserted at r/a=0.77 and squared coherence (γ^2) among the poloidal probes. Note that the position of the innermost probe is at r/a = 0.86 because of the carbon cap structure shown in Fig.1. The squared coherence γ^2 between two signals, X and Y, is defined as

$\gamma^2(\omega) = \langle |X(\omega)Y^*(\omega)| \rangle / \sqrt{\langle |X(\omega)|^2 \rangle \langle |Y(\omega)|^2 \rangle}$,where $X(\omega)$ and $Y(\omega)$ are the Fourier transforms of the two signals and the square bracket denotes ensemble average. As seen from Fig.3, the lower frequency part (f < 20 kHz) has very high coherence against θ -1, which is located on the innermost position. We have measured the radial profile of magnetic fluctuations, changing the probe array position shot-by-shot. Figure 4 shows poloidal magnetic field fluctuations as a function of the minor radius. The power decreases with the increase in the minor radius. Outside LCFS, the poloidal mode number m may be determined from the radial variation of the poloidal field $\tilde{B}_\theta$, assumed to

$$\tilde{B}_\theta \propto r^{-(m+1)}[1+(r/b)^{2m}]$$

,where b is the wall radius (320mm) [8]. From this analysis the poloidal mode number of low frequency *coherent* peak (f~9kHz) observed during the current ramping is inferred to be 4. Two poloidal sets of 24 Mirnov coils are mounted toroidally 180° in

JIPP T-IIU. The mode analysis for the Mirnov probes also shows m=4. On the other hand, high frequency *incoherent* component (of 60-70kHz) is inferred to be $m \sim 10$ at the same phase (Fig.4). Relationship between the incoherent component and plasma transport, in particular, near the edge is under investigation.

SUMMARY

The magnetic field fluctuations just inside the LCFS have been measured by a newly developed movable magnetic probe array in the JIPP T-IIU tokamak. The fluctuations consist of low frequency *coherent* component and relatively high frequency *incoherent* one. The poloidal mode number of the former component is usually to be m = 2 or 3 in constant plasma discharges, but that with m = 4 is only observed in the fast current ramping phase as shown in Fig.2. These are thought to be caused by MHD kink or tearing mode. The latter *incoherent* component has the medium mode number of $m \sim 10$ for 60-70kHz, and seems to be rapidly increased up to appreciable level toward the plasma center as shown in Fig.4. Therefore, the incoherent magnetic fluctuations may play an important role in the core plasma confinement.

Caption of figure

Fig. 1. Schematic of the movable magnetic probe array installed on JIPP T-IIU. The probe array consists of 4 probes (r-1...r-4) arranged every 14mm separation vertically to detect radial magnetic field fluctuations, and 6 probes (θ -1... θ -6) arranged every 7mm separation to detect poloidal magnetic field fluctuations. These probes were installed inside a stainless steel pipe of 13 mm inner diameter and 1mm thickness. The top of the pipe is protected by a carbon/carbon -composite with 20% boron from plasma bombardment. This probe array can be inserted into a plasma beyond LCFS, where the probe position is scanned in the range of r/a = 1.4-0.8.

Fig. 2. Time evolution of CII and H_α line emissions in an NBI heated plasma with the current ramp-up, where the toroidal magnetic field is $B_t \approx 3$ T and line averaged electron density reaches $\overline{n}_e \sim 5 \times 10^{19}\ m^{-3}$. Solid curve shows the case the probe array is inserted in the deepest position of the plasma, and broken one the case it is outside LCFS. Electron and ion temperatures of this discharge are $T_{e0} \sim 1.5$ keV and $T_{i0} \sim 0.9$ keV at the plasma center, and $T_e \sim 0.2$ keV, $T_i \sim 0.2$ keV at r/a $\sim$ 0.8, respectively.

Fig. 3. (Upper figure): Frequency spectrum of poloidal magnetic fluctuations sampled between 211 ms and 221 ms (during the current ramping discharge as shown in Fig. 2.). (Lower figure): Squared coherence (γ^2) of θ -1 probe with other poloidal probes of θ -2, θ -4, and θ -6, where the probe separations of θ 1- θ 2, θ 1- θ 4 and θ 1- θ 6 are 7mm, 21mm and 35mm, respectively. The shadow ranges indicate coherent part (a) 5kHz < f <13 kHz and incoherent one (b) 60kHz < f < 70kHz

Fig. 4. The radial profile of amplitude of poloidal magnetic fluctuations, where (a) corresponds to coherent parts shown in Fig.3 and (b) incoherent one. Solid curves show the predicted relation ($\tilde{B}_\theta \propto r^{-(m+1)}[1+(r/b)^{2m}]$) of $\tilde{B}_\theta$ for m=4 and m=10, respectively.

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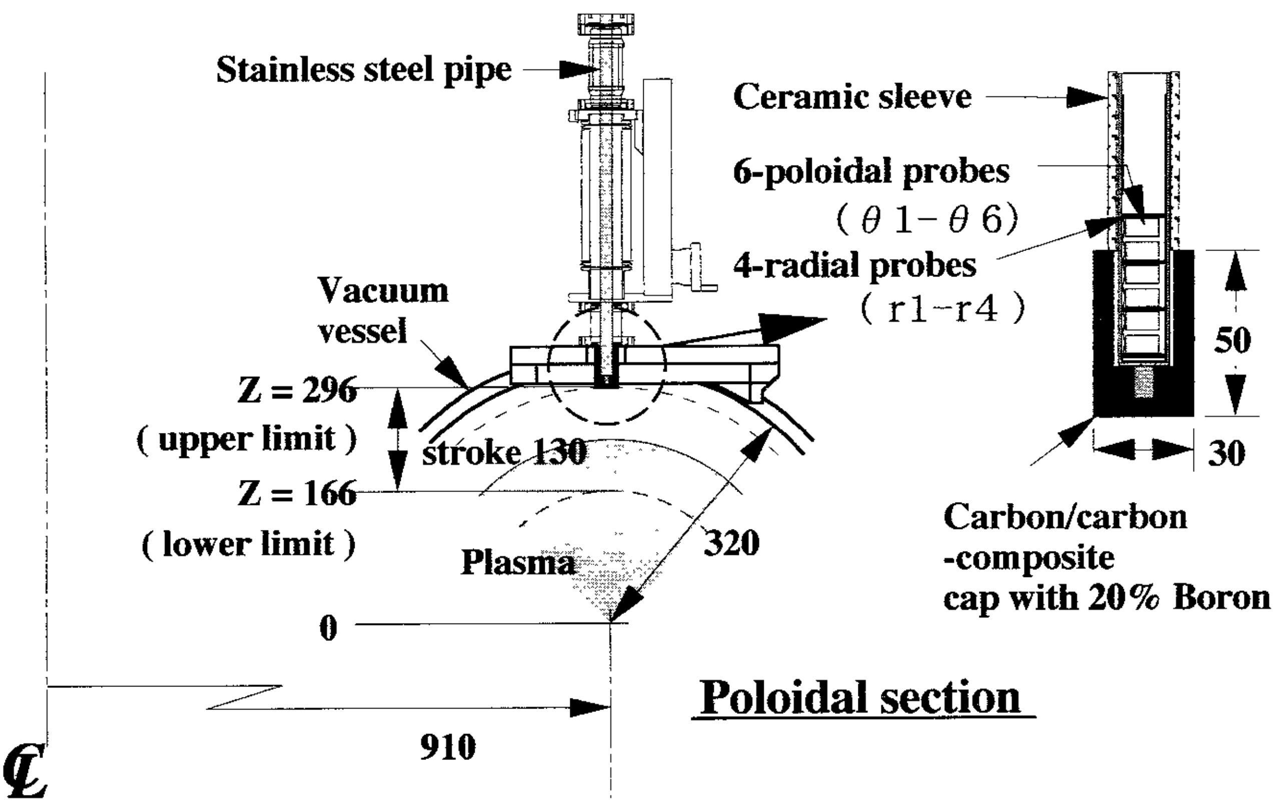
Stainless steel pipe
Ceramic sleeve
6-poloidal probes
(θ1-θ6)
4-radial probes
(r1-r4)
Vacuum vessel
Z = 296
(upper limit)
stroke 130
Z = 166
(lower limit)
Plasma
320
0
50
30
Carbon/carbon -composite cap with 20% Boron
Poloidal section
910
℄

Fig. 1.

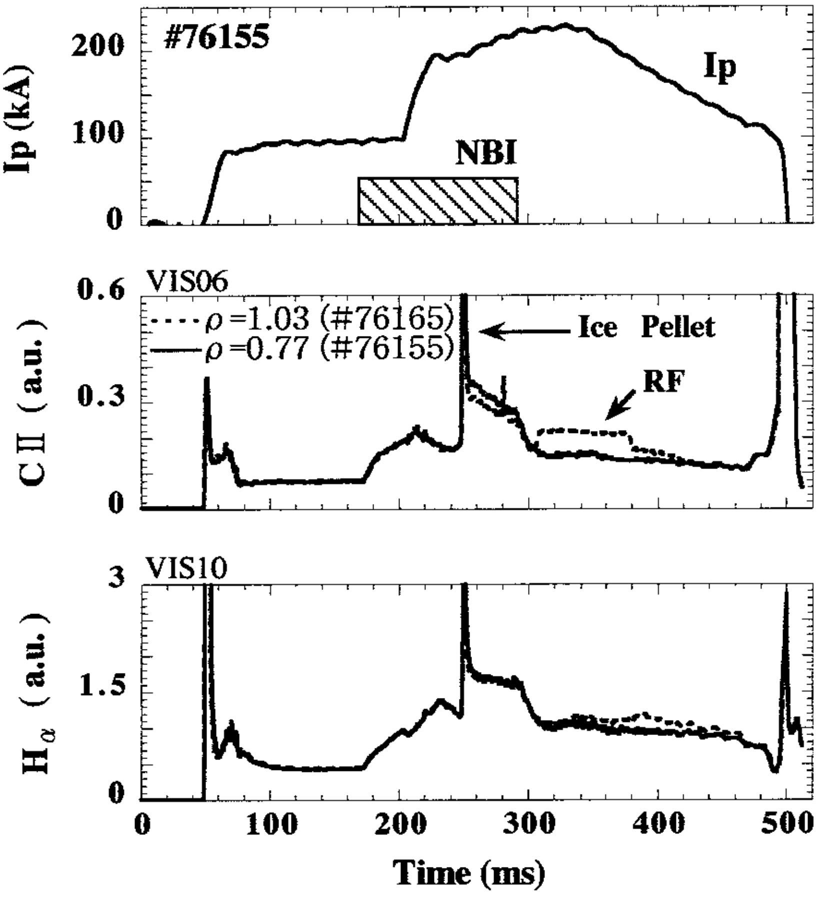
#76155
Ip (kA)
200
100
0
Ip
NBI
VIS06
0.6
0.3
0
C II (a.u.)
ρ=1.03 (#76165)
ρ=0.77 (#76155)
Ice Pellet
RF
VIS10
3
1.5
0
Hα (a.u.)
0
100
200
300
400
500
Time (ms)

Fig.2.

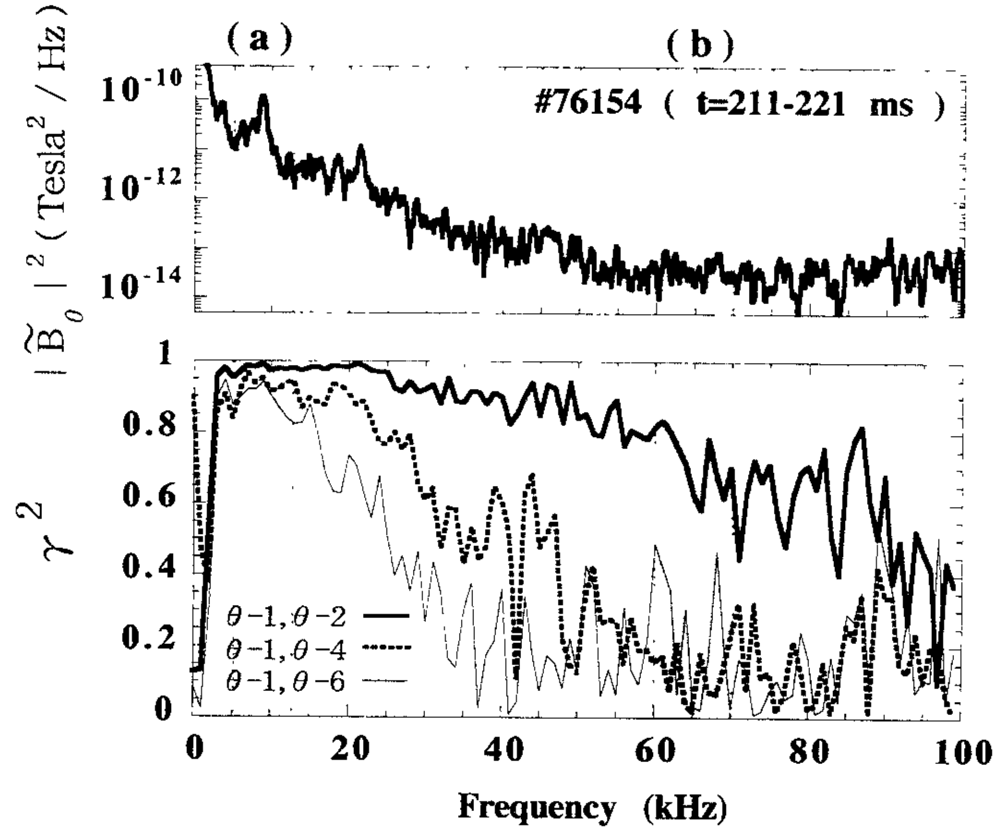
(a)
(b)
#76154 (t=211-221 ms)
$|\tilde{B}_\theta|^2$ ($Tesla^2$ / Hz)
10^{-10}
10^{-12}
10^{-14}
γ^2
1
0.8
0.6
0.4
0.2
0
θ-1, θ-2
θ-1, θ-4
θ-1, θ-6
0
20
40
60
80
100
Frequency (kHz)

Fig. 3.

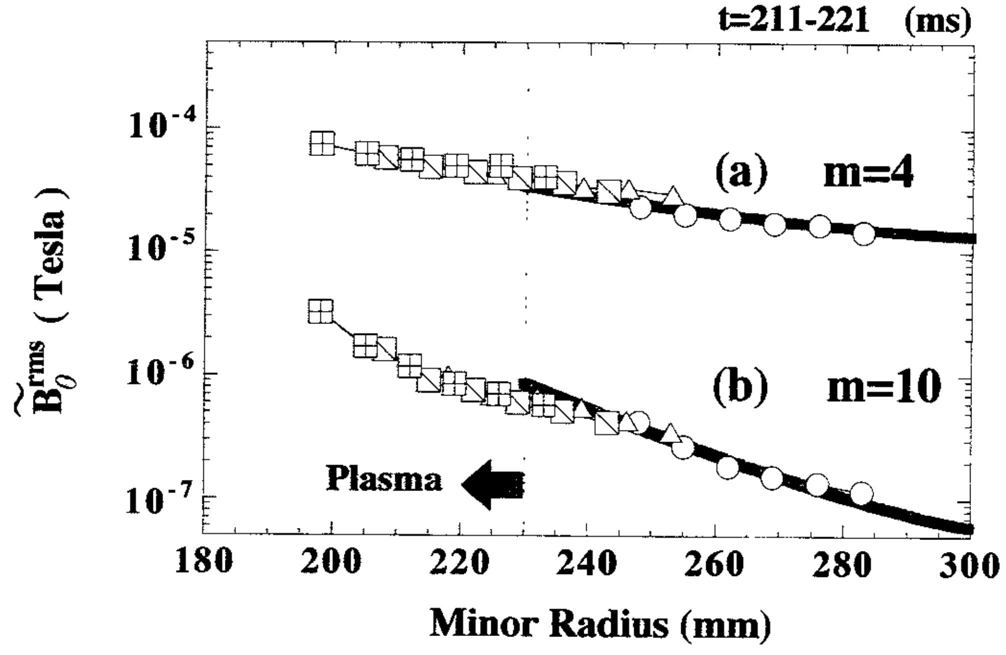
t=211-221 (ms)
$\tilde{B}_\theta^{rms}$ (Tesla)
10^{-4}
10^{-5}
10^{-6}
10^{-7}
(a) m=4
(b) m=10
Plasma
180
200
220
240
260
280
300
Minor Radius (mm)

Fig. 4.

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