COHERENT MODES AND BROADBAND MAGNETIC TURBULENCE IN THE CASTOR TOKAMAK

I. Ďuran[1], J. Stöckel[2], K. Jakubka[2]

[1]*Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic*
[2]*Institute of Plasma Physics, CAS, Prague, Czech Republic*

Abstract

Link between the transport processes and magnetic turbulence in tokamaks is not clearly understood yet. One of the reasons is that the relevant magnetic data directly measured in the central region of plasma column are not available. The aim of this article is to fullfil this gap. The fluctuations of radial magnetic field are monitored by means of array of eight radial magnetic coils well in the plasma interior of the CASTOR tokamak. The measured signal is found to be a superposition of broadband microturbulence and coherent modes (esp. with the poloidal mode number m=2). Standard numerical data processing is applied to characterize these two components individually.

1. Introduction

Within a knowledge of the authors only a few reports dedicated to measurements of magnetic field well in the interior of fusion devices plasmas were published up to now. According to [1], the radial magnetic field fluctuations are measured well in the plasma interior of Tokapole II tokamak, and scaled over the edge safety factor 0.6≤q(a)≤5.0. It was found, that q(a) serves as a control parameter for both the magnetic fluctuation amplitude and the global confinement time. It was also found, that at q(a)≤1, the full fluctuation amplitude is roughly large enough to account for the global confinement using simple estimates of collisionless stochastic magnetic transport. In [2], the internal radial and poloidal magnetic field measurements are performed on CHS Heliotron/Torsatron. The magnetic signals are found to be a superposition of coherent component concentrated in the frequency range less than 40 kHz and incoherent component dominant for frequencies >40 kHz. The radial profiles of both these components are presented. The amplitude of magnetic turbulence is scaled over the NBI and OH input power. Ambition of this paper is to present characteristic properties of magnetic fluctuations on CASTOR tokamak and to try to obtain better insight into a nature of these turbulent processes.

2. Experimental arrangement and calibration

The radial component of the magnetic field B_r is measured by means of a radially oriented array of eight absolutely calibrated coils (the diameter of each is 4.4 mm, the length is 4 mm), spaced in the radial direction by 6.7 mm. The total active length of the array is 51 mm, which represents $\sim$ 60% of the plasma minor radius (in the case with minor radius a=85 mm). In short discharges (t $\leq$ 10 ms) with a reduced plasma current ($I_p \leq 7$ kA), the whole array can be inserted into the plasma column without any damage and plasma is not perturbed significantly. To monitor the MHD activity, the poloidal component of the magnetic field B_θ is measured with a set of 16 Mirnov coils located in SOL. The position of the magnetic diagnostics is shown in the Fig. 1 in the poloidal cross-section view.

The output signals from coils are conditioned by a passive RC integrating circuit to avoid aliasing. Then, the coils signals are simultaneously digitized by a 12 bit A/D converters. The fastest used sampling rate was 0.2 μs/sample. The length of sampling interval was up to 13 ms. All radial magnetic coils are absolutely calibrated. The output voltage of the coil $V = A_{eff} dB_r/dt$ where A_{eff} is effective area of the coil and dB_r/dt is the time derivative of the measured magnetic field. The response of the coils was found to be frequency independent (within 5%) for frequencies (5-300 kHz).

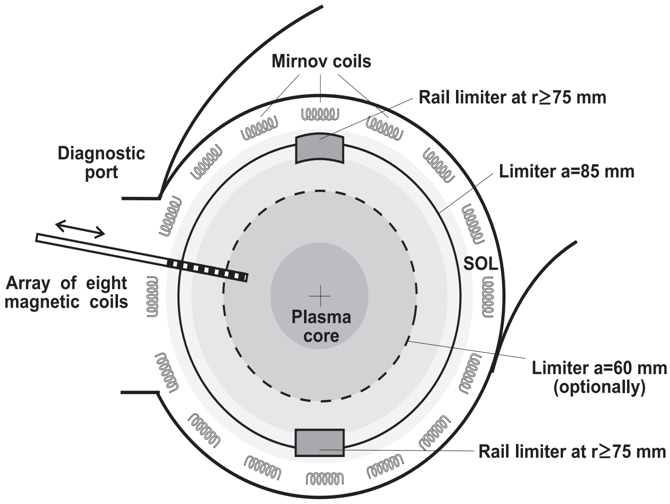

Figure 1. Position of the magnetic probes in the poloidal cross-section of the CASTOR tokamak.

3. Results

The fluctuations of radial magnetic field $\tilde{B}_r$ are investigated on the CASTOR tokamak (major radius R = 0.4 m, minor radius a = 0.085 m or, optionally a=0.060 m, toroidal magnetic field $B_t = 0.5 \div 1.1$ T, plasma current $I_p = 5 \div 20$ kA , safety factor at the limiter position q(a)=2.7 $\div$ 15, loop voltage $U_{loop} \sim 2.5$ V, plasma density $n_e \sim 1 \times 10^{19} m^{-3}$, length of the discharge τ_d = 10 $\div$ 50 ms) during quasistationary part of discharge. Measurements are performed in two experimental setups of CASTOR tokamak device. The solid limiter shapes the plasma to tori with minor radius a=0.085 m (aspect ratio ϵ=4.7) in the first one and with a=0.060 m (ϵ=6.7) in the second one. Simultaneously, a two rail limiters (from the top and the bottom of the poloidal cross-section) can be inserted up to r = 75 mm (see Fig. 1). This two geometrical configurations allow us to study impact of different aspect ratio configurations on the behaviour of magnetic turbulence.

3.1. Frequency spectra

Generally, a two types of frequency spectra are observed depending on discharge conditions as shown in the Fig. 2. Each window displays the eight frequency spectra of the $\tilde{B}_r$-fluctuations measured by the eight coils array in a single shot.

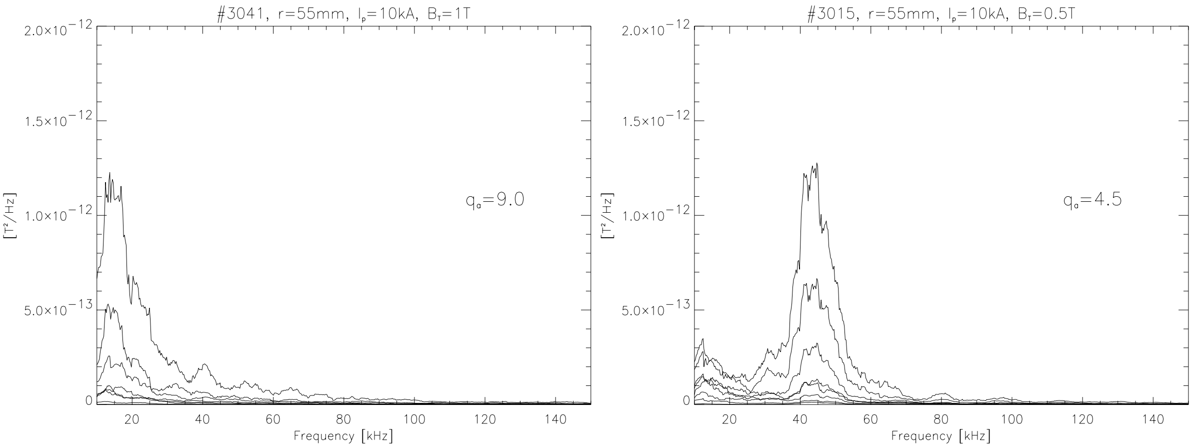

Figure 2. Power spectral densities computed for two shots with the plasma current I_p=10 kA.
Left : B_T=1 T $\longrightarrow$ safety factor q(a)=9.0 Right: B_T=0.5 T $\longrightarrow$ safety factor q(a)=4.5

The left window shows spectra monotonously decaying with frequency. On the other hand, the relatively narrow spectral peak ($\Delta f \sim 10$ kHz) superimposed over the broadband background is clearly identified around the dominant frequency 45 kHz in the right window for all the 8 signals. In general, presence of some dominant frequency in the power spectra is typically observed only for shots with low safety factor q(a)<8, when the MHD unstable magnetic surface with q=2 appears within the plasma column. The Mirnov coils measurements revealed that the dominant frequency in the $\tilde{B}_r$ spectra is associated with the poloidal rotation of the m=2 magnetic island within the plasma column.

3.2. Correlation analysis

The spectral band related to the rotation of the m=2 magnetic island (coherent mode) and to the broadband part of the spectrum (broadband microturbulence) is analysed individually to identify dimensions and eventual propagation of the $\tilde{B}_r$ structures in the radial direction. It was found out that probes signals relevant to the coherent mode are highly correlated $\sim$ 0.9 over the whole probes array. This means that characteristic length of these coherent structures is longer or comparable with the minor radius. In the case of signals related to the broadband microturbulence the correlation is also relatively high but spatially localized. The correlation length in the radial direction is $\sim$ 2 cm. Moreover, the radial propagation of broadband microturbulence in outward direction is observed with velocity of about $\sim$ 5 km/s. On the other hand, no such phenomenon is seen for coherent mode as expected.

3.3. Amplitudes and radial profiles of the $\tilde{\mathrm{B}}_\mathrm{r}$-fluctuations

The radial profiles of $\tilde{B}_r$-fluctuations are analysed for the broadband fluctuations and for the coherent mode individually via filtration in frequency domain. The next two figures display the radial profiles of $\tilde{B}_r$ signals corresponding to the coherent mode $\tilde{B}_r^{coh}$ for two geometrical setups (a=85 mm and a=60 mm). Each curve is obtained by averaging over five shots with the same safety factor (q(a)=5.4 - left window, q(a)=5.8 - right window), with displayed error bars.

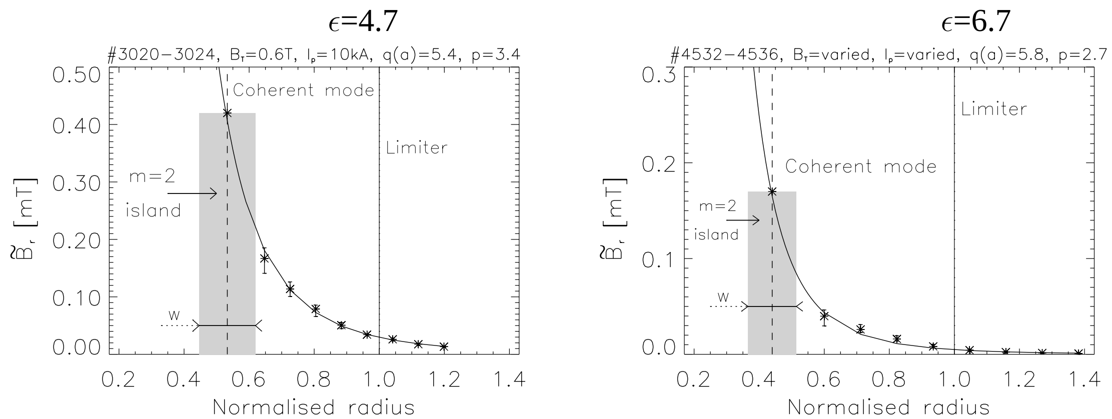

Figure 3. Radial profiles of $\tilde{B}_r^{coh}$ signals for two geometrical configurations of CASTOR tokamak: a=85mm - left window, a=60mm - right window. Shaded rectangles denote numerically computed positions and widths of m=2 magnetic island. The hight of the rectangle is chosen to match the numerical fit of measured values.

The radial profiles of $\tilde{B}_r^{coh}$ decrease as $\sim$ (r/a)$^{-4}$ for a=85 mm as well as for a=60 mm. However, the amplitude of the observed signal is substantially lower for the larger aspect ratio configuration (a=60 mm - right window) at all radial positions. A very good reproducibility of shots is depicted by small extension of all error bars. Moreover, this also says that the amplitude of coherent mode is determined by safety factor and not by individual plasma parameters (I_p, B_T) for the given geometrical configuration. It is especially seen from the right window, where the plasma parameters (I_p, B_T) were changed substantially from the shot to shot while q(a) was always kept constant, and no substantional variation in $\tilde{B}_r^{coh}$ was observed.

The radial profiles of broadband microturbulence $\tilde{B}_r^{micro}$ are shown in next two figures. To characterize this part of the magnetic signals we performed two series of $\approx$ 70 shots with varied plasma parameters ($I_p = 3 \div 12kA,\ B_T = 0.4 \div 1\ T, q(a) = 2.8 \div 15$), the first for small (left window) and the second for large aspect ratio configuration (right window).

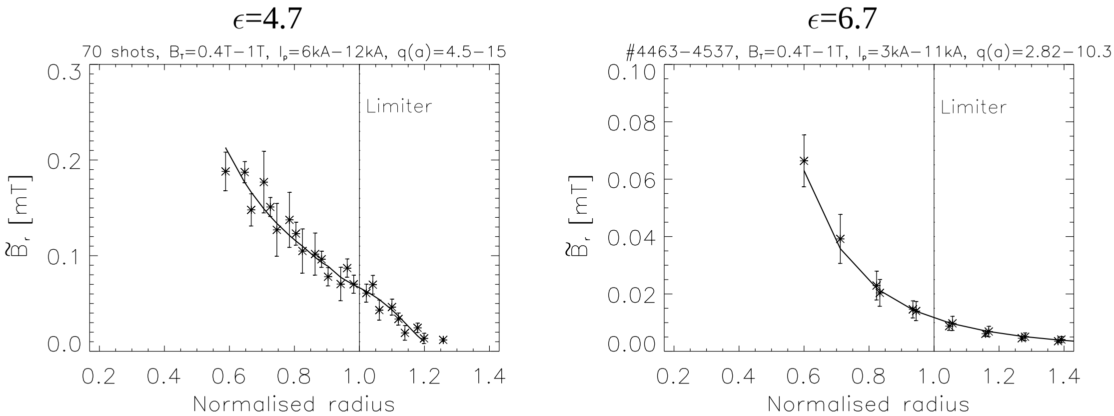

Figure 4. Radial profiles of $\tilde{B}_r^{micro}$ signals related to the broadband microturbulence for two geometrical configurations of CASTOR tokamak: a=85mm - left window, a=60mm - right window. In the left window, the increase of $\tilde{B}_r^{micro}$ around the limiter is evident.

It is clearly seen, that for given geometrical configuration the level of $\tilde{B}_r^{micro}$ fluctuations is independent on plasma current, toroidal magnetic field nor any combination at these two quantities. The same as for the level of $\tilde{B}_r^{coh}$, the stabilizing effect of larger aspect ratio is clearly seen. Moreover, an interesting phenomenon is systematically observed for smaller aspect ratio configuration and that is the increased level of $\tilde{B}_r^{micro}$ close to the limiter radius. This enhanced level of microturbulence could be possibly attributed to the current fluctuations in the scrape of layer that are measured by means of miniature Rogowski coil on the CASTOR tokamak.

4. Conclusions

The magnetic turbulence is monitored and characterized with radial and poloidal resolution on the CASTOR tokamak. Measured level of $\tilde{B}_r$ fluctuations $0.04 \div 0.3\ mT$ is sufficient to account for particle and energy transport in CASTOR. According to the Rechester-Rosenbluth formula, these values of $\tilde{B}_r$ imply the diffusion coefficient $\sim 1\ m^2/s$, which is typical for tokamak plasmas. Observed magnetic turbulence is composed from at least two components, the broadband fluctuations caused by microinstabilities and the coherent mode. The presence of the coherent mode is associated with the poloidal rotation of especially m=2 magnetic island within the plasma column. Both these components are treated and characterized separately. The level of $\tilde{B}_r^{coh}$ connected with presence of global esp. m=2 magnetic islands is governed by safety factor. Level of $\tilde{B}_r^{micro}$ was found to be independent on I_p (3÷12 kA) and B_T (0.4÷1 T). Stabilizing effect of larger aspect ratio configuration was observed with factor $\sim$ 3 for $\tilde{B}_r^{coh}$ as well as for $\tilde{B}_r^{micro}$.

References

[1] D.E. Graessle, S.C. Prager and R.N. Dexter: Phys. Fluids B **3**(9), 1991
[2] T. Oike, K. Toi, S. Ohdachi, S. Sakakibara et al: *Proceedings of 1996 ICPP*, Nagoya, 1996
[3] J. Stöckel, et al.: *Proceedings of 1996 ICPP*, Nagoya, 1996