J. Plasma Fusion Res. SERIES, Vol.1 (1998) 259–262

Recent Observations of MHD Instabilities on W7-AS

ANTON Mathias*, KLINGER Thomas[1], HÄSE Marcus, ZOLETNIK Sandor[2], GEIGER Joachim, GÖRNER Caio, HARTFUSS Hans-Jürgen, JAENICKE Rolf, WELLER Arthur, W7-AS Team, NBI Group and ECRH Group

Max-Planck-Institut für Plasmaphysik, EURATOM Ass., Boltzmannstr. 2, D-85748 Garching, Germany

[1]*Institut für Experimentalphysik, Christian-Albrechts-Universität Kiel, Olshausenstr. 40-60, D-24098 Kiel, Germany*

[2]*KFKI-Research Institute, Department of Plasma Physics, P.O. Box 49, Budapest 114, Hungary*

(Received: 30 September 1997/Accepted: 23 December 1997)

Abstract

Magnetic fluctuations are observed in ECRH plasmas on the W7-AS stellarator which can not be identified with any known type of MHD mode. We investigate this type of fluctuation using cross correlation and Fourier methods as well as phase space analysis from dynamical systems theory. In spite of its weakly turbulent character, a spatial structure can be identified. The development of the spatial structure coincides with a decrease of the energy confinement time.

Keywords:

mirnov probes, magnetic fluctuations, MHD instabilities, weakly developed turbulence, phase space analysis

1. Introduction

Magnetic fluctuations on W7-AS are measured using poloidal arrays of 8 or 16 Mirnov coils at different toroidal locations. Sampling rates are 250 – 330 kHz. The spatio-temporal behaviour of the Mirnov data is routinely analysed using Fourier techniques, singular value decomposition and cross correlation methods [1]. In addition, we use Lomb's normalized periodogram [2] in order to determine the poloidal structure. Instead of the poloidal mode number m which is well-defined only for rational values of the rotational transform ι we use the notation $k_\theta r_f$, where k_θ is the poloidal wavevector and r_f the radial position of the perturbation.

This is motivated by the facts that a) it is an open question whether the signals observed with magnetic diagnostics in electron cyclotron resonance (ECR) heated plasmas are due to coherent mode activity or to fluctuations in a narrower sense and b) there are usually no low m, n rational values of ι inside the last closed magnetic surface.

If we assume a current perturbation along magnetic field lines, we obtain a heuristic formula for the frequency of the magnetic fluctuations $\tilde{B}_\theta$ in the laboratory frame which reads

$$f_{\rm lab} = \frac{v_{\rm dia}(r_f) + v_{E\times B}(r_f)}{2\pi r_f} \cdot k_\theta r_f \qquad (1)$$

where $v_{\rm dia}$ is the electron diamagnetic drift velocity and $v_{E\times B}$ is the $\boldsymbol{E} \times \boldsymbol{B}$ drift speed of the electrons. Experimentally, $v_{\rm dia}$ is obtained from temperature and density profiles measured by Thomson scattering whereas $v_{E\times B}$ is determined using charge exchange recombination spectroscopy [3].

**Corresponding author's e-mail: mathias.anton@ipp.mpg.de*

2. Observations

Series of ECR heated discharges have been produced in order to investigate the dependence of the energy confinement time τ_E on the rotational transform at the plasma boundary ι_a. Parameters of these discharges are $0.33 < \iota_a < 0.36$, $B_\phi = 2.5$ T, $0 < B_z < 22$ mT, $P_{ECRH} \approx 480$ kW and $n\ell \approx 4 \times 10^{19}$ m^{-2}.

Figure 1 displays the normalized cross correlation function [2] of Mirnov signals as a function of the time lag τ and the poloidal position of the probes. The energy confinement time of discharge #38806 ($\iota_a = 0.339$, $B_z = 0$) is two times larger than τ_E of #38808 ($\iota_a = 0.345$, $B_z = 0$). For #38808, a pronounced poloidal structure with $k_\theta r_f \approx 3$ rotating in the electron diamagnetic drift direction is observed. The power spectrum of #38806 is broader compared to #38808 (see Fig. 5) with a peak between 10 – 20 kHz.

In Fig. 2, we compare f_{lab} Eq. (1) to Mirnov spectra for two discharges with $\iota_a = 0.349$ (#39218) and $\iota_a = 0.361$ (#39235, both with $B_z = 220$ mT). As was the case for #38806 and #38808, the spectrum of the discharge with the lower τ_E exhibits more structure and a lower average frequency (#39235, darker curves in Fig. 2). Note the low "shear" of f_{lab} for #39235, which possibly explains the relatively narrow peak in the Mirnov spectrum at $f \approx 20$ kHz.

In a similar discharge (#39911, $B_\phi = 2.5$ T, $\iota_a = 0.345$, $P_{ECRH} = 350$ kW, $n\ell \approx 2 \times 10^{19}$ m^{-2}) temperature fluctuations were observed using electron cyclotron emission (ECE) diagnostics [4]. Magnetic and temperature fluctuations at $f \approx 40$ kHz are correlated. The maximum amplitude of these fluctuations is localised at an effective radius of $r_{eff} \approx 7$ cm. Frequency and radial position are consistent with Eq. (1) as seen from Fig. 3. The poloidal structure inferred from Mirnov data is $k_\theta r_f \approx 3$.

In discharge #40365 ($\iota_a = 0.523$, $P_{ECRH} = 450$ kW) density fluctuations with a frequency of approx. 7 kHz were observed using a Li-beam probe [5]. They extend 1 cm inside and 3–4 cm outside the last closed magnetic surface (Fig. 4). The poloidal structure of the

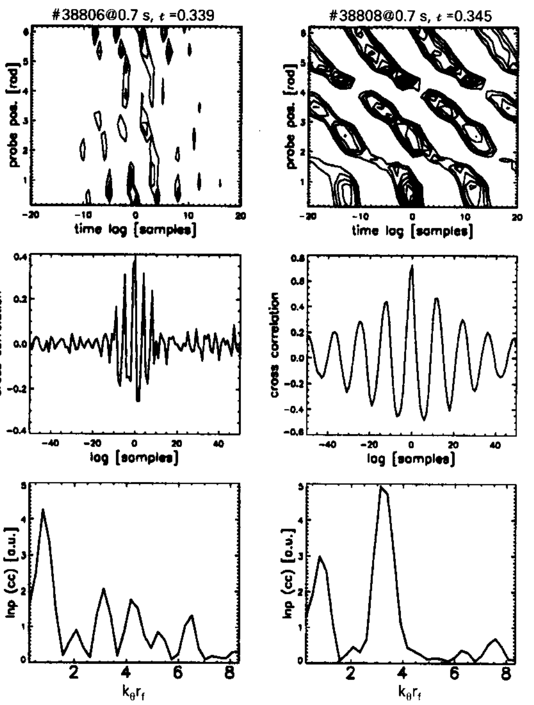

Fig. 1 Left: #38806, right: #38808. First row: cross correlation as a function of time lag τ (1 sample = 5 µs) and poloidal position, second row: cc of two neighbouring probes, third row: lomb periodogram of cc (τ =0, θ).

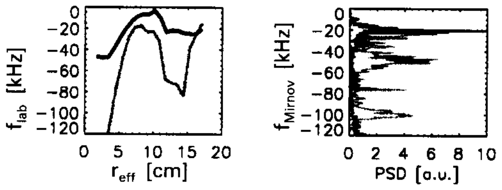

Fig. 2 f_{lab} Eq. (1) (left) compared to Mirnov spectra (right) for #39218 (light curves) and #39235 (dark curves).

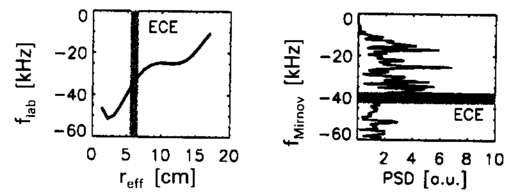

Fig. 3 like Fig. 2, but for #39911, bars indicating the radial position and frequency of T_e-fluctuations correlated with $\tilde{B}_\theta$.

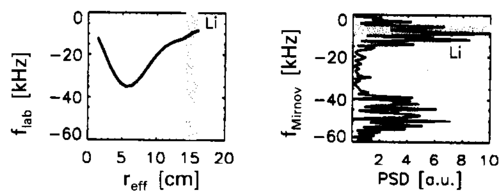

Fig. 4 like Fig. 3, but for #40365, bars indicating radial position and frequency of n_e-fluctuations correlated with $\tilde{B}_\theta$.

magnetic perturbations in this frequency range is $k_\theta r_f \approx 2$, again consistent with Eq. (1).

3. Phase Space Analysis

Broadened but structured (*i.e.* non-power law) spectra are considered as an indicator for weakly developed turbulence [6]. Dynamical systems theory provides numerous instruments to characterize temporal behaviour [7].

We have applied an embedding procedure the basic idea of which is to switch from time evolution to geometry in phase space, where the time enters as a parameter only. The basic assumption is that the dynamics is governed by a set of autonomous ordinary differential equations, where the full set of time-dependent variables span the phase space. This allows to distinguish between noise and strong tubulence (almost infinite dimensional), weakly developed turbulence (high dimensional), and regular dynamics (low dimensional).

The phase space geometry (the attractor) is reconstructed from the time evolution of $X(t)$,

$$X(t) = [x(t), x(t+\tau), x(t+2\tau), \dots, x(t+(d-1)\tau)] \quad (2)$$

where $x(t)$ is the time series of one single Mirnov coil signal. To perform an optimal embedding, we apply the fill-factor criterion described in Ref. [8] which yields the time lag τ. The embedding dimension d is estimated by calculating the correlation integral [9,10].

We have investigated time series of 32 k length each from discharges #38806, #38808 (compare Fig. 1) and #39727 (B_ϕ = 2.5 T ι_a = 0.334, P_{ECRH} = 350 kW, $n\ell$ = 5 × 10 ^{18} m^{-2}). The power spectra (signal and noise) and the visualization of the attractors are displayed in Fig. 5.

The phase space Fig. 5(a) shows just a cloud of scattered points hinting stochastic behavior. We note however in Fig. 5(b) a certain distortion of the phase space structure. Both data sets (a) and (b) are unlikely to correspond to a coherent mode structure, it rather appears to be a weakly turbulent regime.

In Fig. 5(c) fluctuation data of a state where a coherent mode is established are shown. Correspondingly, the power spectrum is sharply peaked. We obtain a phase space reconstruction that clearly shows a limit cycle, the phase space attractor of a regular oscillation.

The conclusion that both data sets (a) and (b) are not due to a coherent mode structure, in contrast to (c), is confirmed by a detailed analysis of the corresponding fill factors and correlation integrals.

4. Summary

MHD activity in ECR heated plasmas of W7-AS appears to be governed by weakly turbulent behaviour. This turbulence can exhibit a pronounced poloidal structure and can be correlated with temperature and density fluctuations. Changes of frequency or poloidal

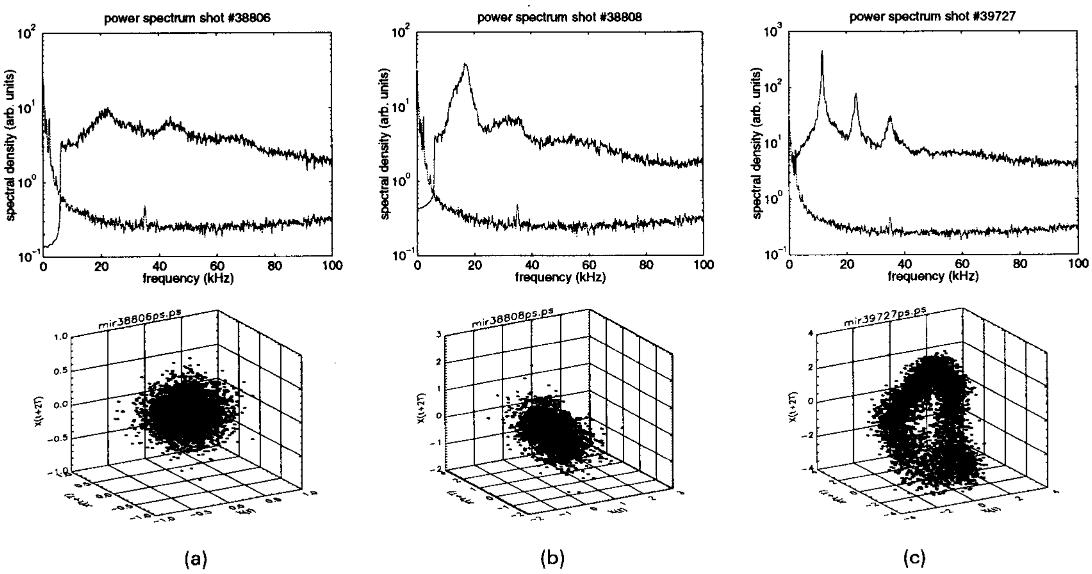

Fig. 5 Power spectra of Mirnov signals and noise (first row) and phase space diagrams for three discharges. (a) left: #38806, (b) middle: #38808, (c) right: #39727.

structure of the magnetic perturbations which coincide with a change of the energy confinement have been observed. Whether the magnetic fluctuations are relevant for transport remains the subject of future work.

References

[1] M. Anton, R. Jaenicke, A. Weller, J. Geiger, W7-AS Team, NBI- and ECRH-Groups, Europhysics Conference Abstracts 21 **A**, Part IV, 1645 (1997).

[2] W. H. Press *et al.*, *Numerical Recipes in FORTRAN*, 2nd ed., Cambridge (1992).

[3] J. Baldzuhn, W. Ohlendorf and W7-AS Team, Rev. Sci. Inst. **68**, 1020 (1997).

[4] S. Sattler, H. J. Hartfuß and W7-AS Team, Phys. Rev. Lett. **72**, 653 (1994).

[5] G. K. McCormick, S. Fiedler, G. Kocsis, J. Schweinzer and S. Zoletnik, Fusion Engineering and Design **34-35**, 125 (1997).

[6] P. Manneville, *Dissipative Structures and Weak Turbulence*, Academic Press, San Diego, 1990.

[7] H. D. I. Abarbanel, *Analysis of Observed Chaotic Data*, Springer, New York, 1996.

[8] T. Buzug and G. Pfister, Physica D **58**, 127 (1992).

[9] P. Grassberger, Phys. Lett. A **97**, 224 (1983).

[10] J. Theiler, J. Opt. Soc. Am. A **7**, 1055 (1990).