Spectral Analysis of Density Fluctuations on Castor Tokamak

L. Kryška, M. Člupek, J. Stöckel

An importance of the edge regions in tokamaks is becoming increasingly apparent. The edge region serves as a barrier for transport losses from the plasma interior, and therefore, it could play an essential role in an overall description of the global particle and energy confinement.

Recent experiments have shown that the edge region is highly turbulent. The relative level of density fluctuations reaches the value $\tilde{n}/n=0,2-0,5$ [1,2,3] and the level of the poloidal electric field fluctuations is in the range of 10-20V/cm. The existence of the edge electrostatic fluctuations results in a fluctuation-induced flux, which seems to be generally responsible for global particle losses and, under some conditions, even for global energy losses in tokamaks [4] . However, the nature of the electrostatic fluctuations is still poorly understood and any additional informations about the turbulent properties of the plasma edge might be desirable.

Here, we report preliminary results on the spectral characteristics of the edge electrostatic fluctuations in CASTOR tokamak, using Langmuir probes. In the simplest case, the power spectral density **S(f)** as the function of the frequency (a frequency spectrum) can be deduced by Fourier analysis of the signal from a single Langmuir probe. However, to get an information about spatial distribution of the fluctuations, one has to use at least two probes. In this case, the spectral power density **S(k,f)**, resolved in wavenumbers and frequencies, can be estimated, using the following philosophy:

1) The signals from the two Langmuir probes are analyzed by the digital fast Fourier transform for a set of frequencies f_n.

2) Then, the phase difference between each Fourier component $\Theta(f_n)$ is calculated. The phase difference, divided by the distance between the probes **d**, represents the local wavenumber $\mathbf{k}(f_n)$. This set of $\mathbf{k}(f_n)$ can not be still simply

related to the dispersion relation of the fluctuations, since, in a turbulent medium, any deterministic relation between the frequency and the wavenumber doesn't exist.

3) To obtain a statistical distribution of these "local" wavenumbers, this procedure, desribed in points 1) and 2), has to be repeated either for many tokamak discharges (e.g. [5]), or for many realizations, monitored during a stationary phase of a single discharge. Then, the statistical distribution of $\mathbf{k}(f_n)$ can be taken as an approximation of the conventional spectral density. We have choosen here the second possibility , which is described in detail in [6] and [7].

EXPERIMENTAL ARRANGEMENT

The experiment was performed on CASTOR tokamak [8] (the major/minor radius R/a=40/8.5cm) at $B_T = 1T$, $I_p = 12kA$ and density $n_e = 3-4{\times}10^{16} m^{-3}$.

The two Langmuir probes were installed in the scrape-off layer (r= 90 mm). The probes were separated in the poloidal direction, the distance between them was d = 0.7 cm. The probes were negatively biased to monitore the ion saturation current, which is proportional to the local electron density.

The probe signals were digitized by a two channel transient recorder, using the sampling period $\delta t = 0.5us$. 4096 samples were stored for each probe. The data were processed by the following way: Every record was divided into 32 realizations, each containing 128 samples. Using the fast Fourier transform algorithm we get spectra of each realization with the maximum frequency $f_{NYQ} = 1/2\delta t = 1MHz$ (the Nyquist frequency) and frequency resolution $\delta f = 1/T \doteq 15$ kHz (where T is the length of an individual realization, $T = 6.4{\times}10^{-5}$ sec). The maximum resolution in wavenumbers is given by the number of the realizations. Then, following [6,7], we performed the spectral analysis to estimate $S(\mathbf{k},\mathbf{f})$.

EXPERIMENTAL RESULTS

Fig.1 depits an estimate of the statistical distribution $S(\mathbf{k},\mathbf{f})$ for the standard ohmic discharge on the

CASTOR tokamak. We see that in the given frequency range, both positive and negative values of wavenumbers can be identified. Most of the k-values are negative, in concordance with observations made on other tokamaks for r/a > 1. It corresponds to the wave propagation in the direction of the ion diamagnetic drift. We see that the distribution of the wavenumbers for a given frequency is noticeably broad, which implies a turbulent character of the density fluctuations. Note also that the **k**-distribution has two peaks for the most of the frequencies. Another characteristic feature is that the distance of a maximum of the $\mathbf{k}(\mathbf{f}_n)$ - distribution from the axis k = 0 increases with the frequency.

It should be noted that the highest frequency contributions to S(k,f) consist of preamplifier and digitizing noise, and that the noise in one channel is statistically independent on the other channel. For such noise one expects the phase of the sample cross-power spectrum to be uniformly distributed from $-\pi$ to $+\pi$.

The statistical distribution **S(k,f)** for LHCD discharge is shown in Fig.2. We see that the power spectral density becomes noticeably narrower along **k**-axis with respect to the OH case. Note also the peak at $f_n = 30$kHz, which may identify a coherent behaviour of the density fluctuations at LHCD. However, to check this fact properly, additional LHCD shots have to be analyzed.

An integration of **S(k,f)** over the calculated wavenumbers yields the frequency spectrum **S(f)**. Fig.3 shows comparison of that frequency spectra at OH and LHCD shots. We see that the fluctuations with frequencies above f= 40kHz are noticeably reduced during LHCD. An integration of **S(k,f)** over **k** and f, yielding the estimate of the total power associated with the density fluctuations P_f, shows that $P_f^{LHCD} \doteq 0.75 P_f^{OH}$. It corresponds to results of our previous fluctuation measurements, performed by the analog correlation technique [8].

Finally, Fig.4 compares the plots of the mean wavenumber k versus frequency for OH and LHCD cases. The both plots have approximately the same shape. The $\overline{k} = \overline{k}(f)$ plot represents roughly a statistical dispersion relation for the density fluctuations. Since this relation is roughly linear up to f = 100 kHz, one can estimate a mean poloidal velocity of density fluctuations from its slope. Here, we get $v_{pol} \doteq 3$km/sec which well agrees with previous crosscorrelation measurements ($v^{cross} \doteq 3.5$ km/s), performed recently on CASTOR tokamak (see [9]). However, in a general case the correct estimate of the propagation velocity needs a power weighting of individual contributions v_{phase}-components [7].

SUMMARY

The spectral analysis of the space/time varying density fluctuations has been performed on CASTOR tokamak, using a double Langmuir probe. We have estimated the statistical power density **S(k,f)**, the frequency spectra and the statistical dispersion relation.

Moreover, we have compared the spectral characteristics of the density fluctuations for a standard ohmic discharge and for a shot with the lower hybrid current drive. We have found that the total power associated with density fluctuations is reduced in LHCD case. Is seems that a non-negligible contribution to this reduction is caused by a narrowing of the spectral power density **S(k,f)** along k-axis. It indicate that not only level but also a character of the edge fluctuations change at LHCD.

Finally, it should be noted that the shape of the statistical distribution of the local wavenumbers is only partially related to the exact form of the spectral density function as it has been demonstrated by a numerical simulation in [10]. Nevertheless, the desribed spectral analysis reflects the correct mean value **k(f)** and the rms deviation of the fluctuation wavenumbers.

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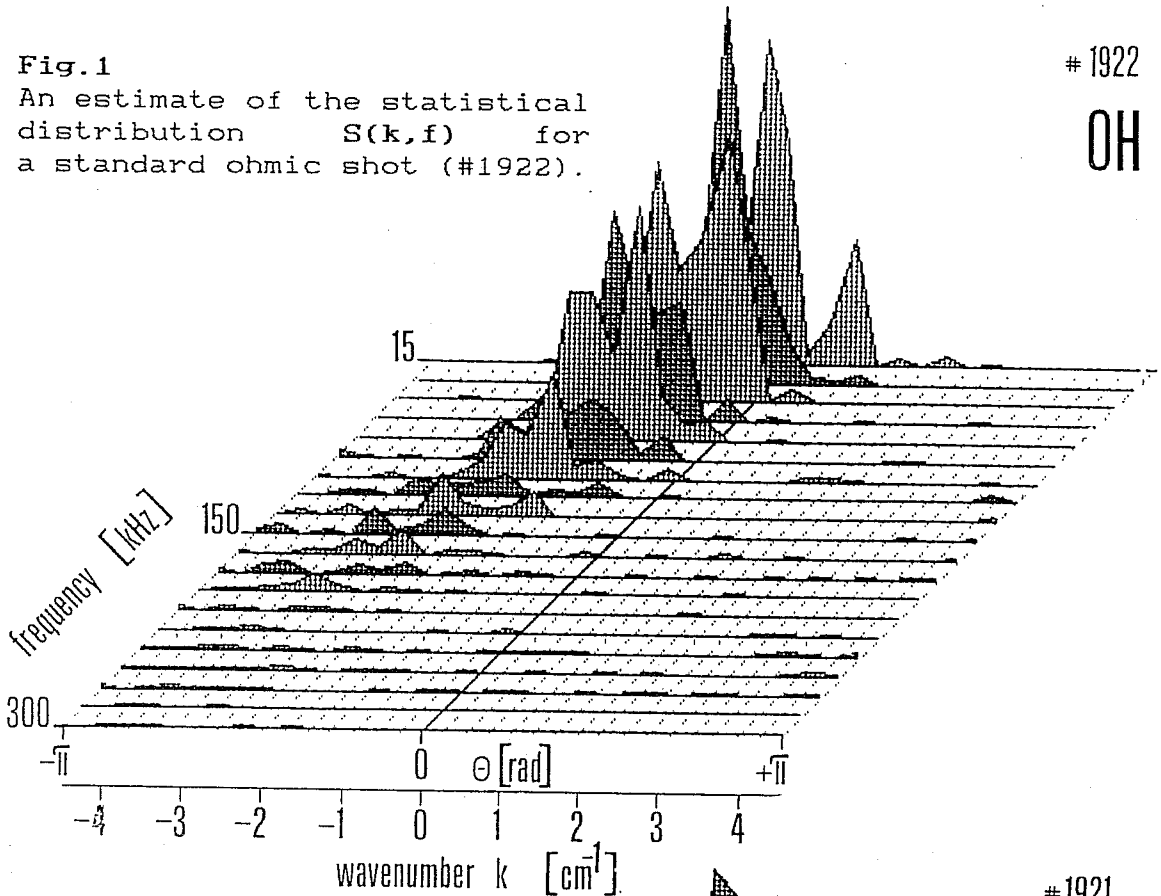

Fig.1
An estimate of the statistical distribution S(k,f) for a standard ohmic shot (#1922).

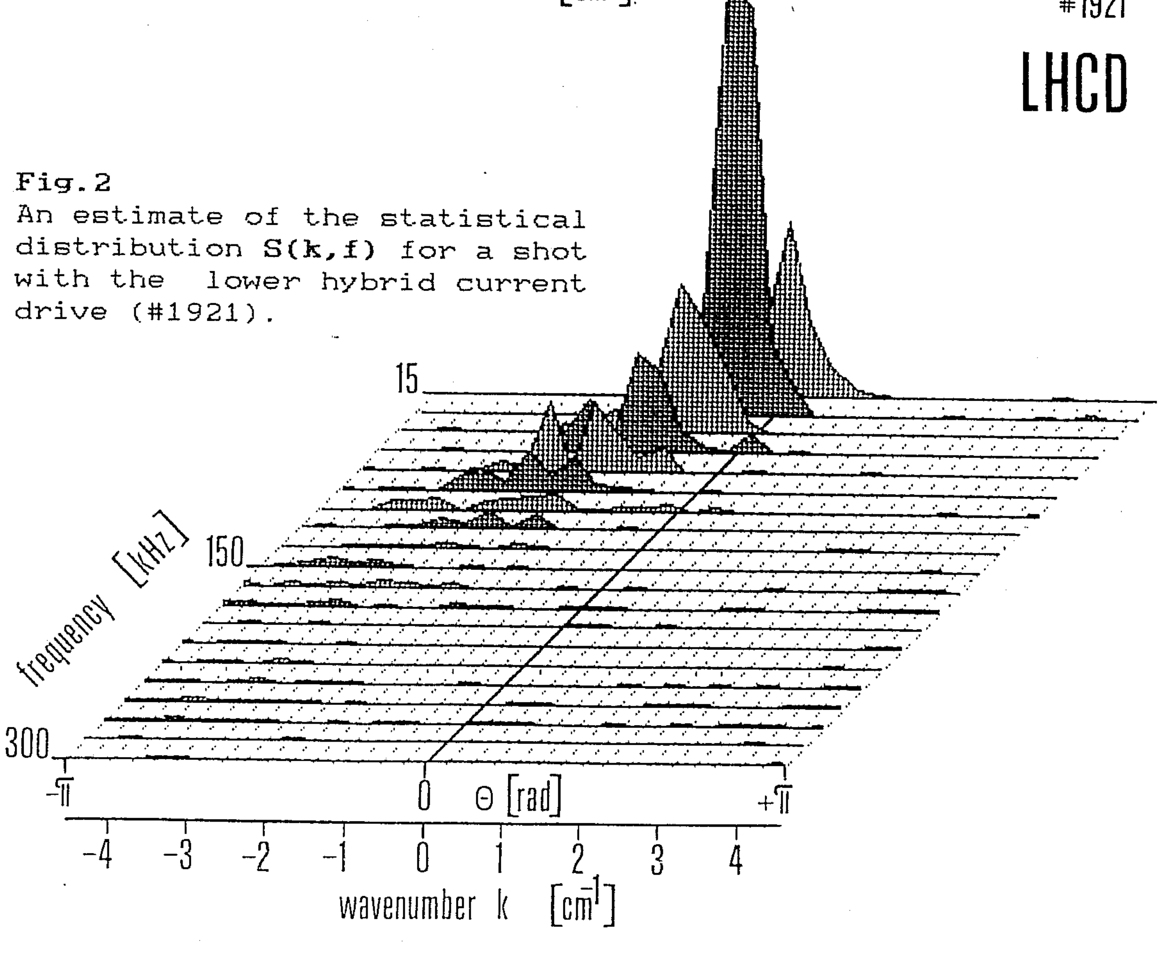

Fig.2
An estimate of the statistical distribution S(k,f) for a shot with the lower hybrid current drive (#1921).

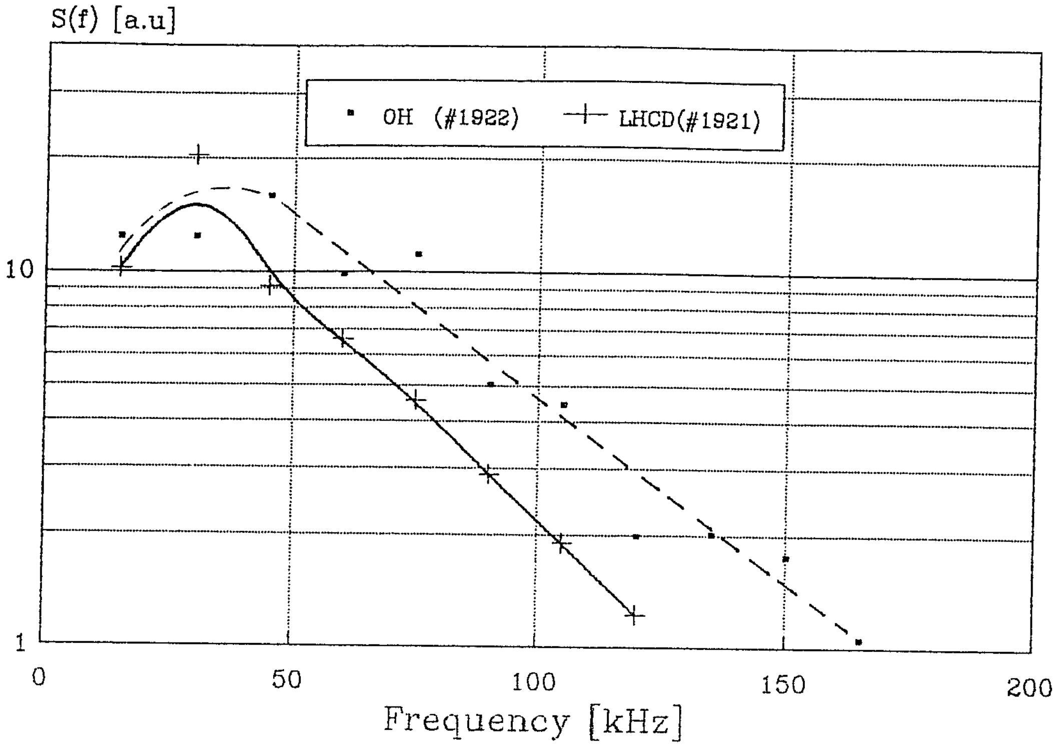

Fig.3
Comparison of the power frequency spectra S(f) for an ohmic (#1922) and LHCD (#1921) shots. The decrease of S(f) at low frequencies is caused by a limited bandwidth of the input preamplifier of the transient recorder.

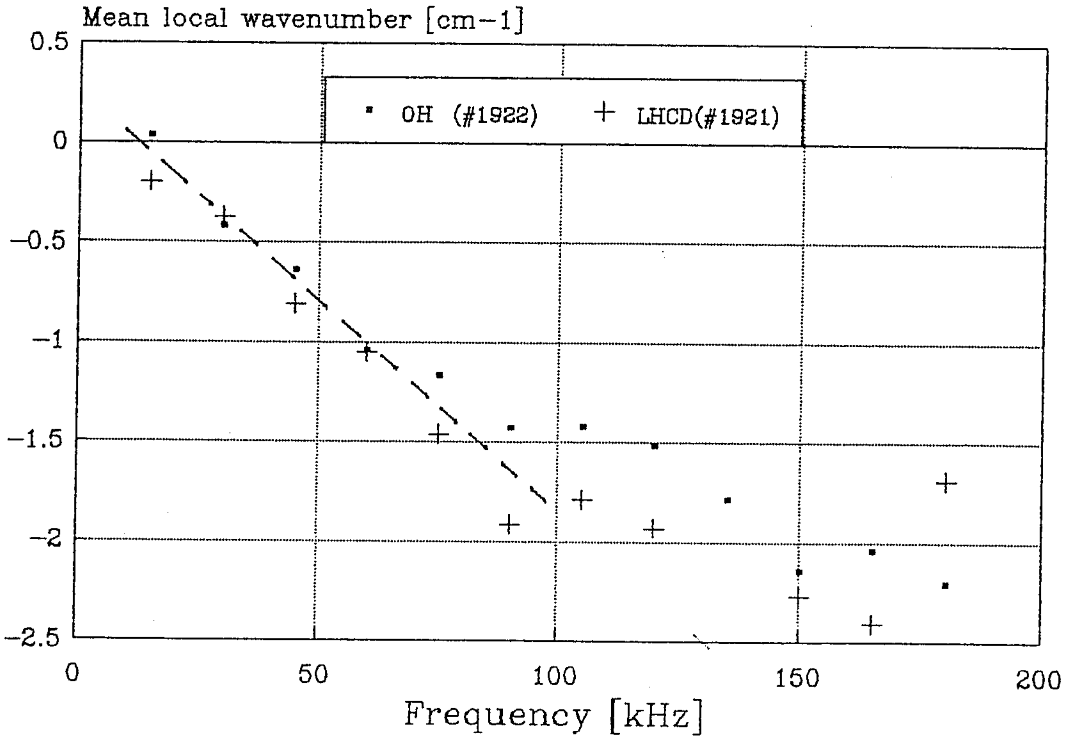

Fig.4
The statistical dispersion relation of density fluctuations at OH and LHCD regimes. The propagation velocity of the fluctuations in the poloidal direction can be roughly estimated from the slope of the dashed line.