SIMULATION OF CO_2-LASER SCATTERING FROM PLASMA FLUCTUATIONS IN FT-2 TOKAMAK

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1. Introduction and numerical approach

For far-forward laser scattering diagnostics the reconstruction of plasma pattern from the scattering spectra relates to the ill posed problem because of the signal averaging over the extended non-uniform scattering region. To interpret the experimental data the direct numerical modelling of plasma fluctuations seems very productive. This was undertaken for the first time in [1] to evaluate spectral broadening caused by extended scattering volume. However, a simplified model has been employed for tokamak drift turbulence.

Recently the CO_2-laser scattering experiment has been carried out in the FT-2 tokamak (R=55 cm, a=8 cm) using homodyne detection with parallel K-analysis [2]. The FT-2 access suggests a favour of use the variable incident beam positions over the major radius. This opens up new possibilities to extract the plasma fluctuation pattern via scattering signal simulation. The different 2D models for small-scale fluctuations have been considered to compute the spectra and compare the results with the measurements. A superposition of Gaussian shaped filaments along the magnetic field lines are proposed to depict the tokamak fluctuations $\delta n(x,y,t)$:

$$\delta n(x,y,t) = \sum_i \delta n_i(t) \exp[-\frac{(x-\Delta_i(t)\cos(\theta_i(t)))^2}{\Lambda_i^2} - \frac{(y-\Delta_i(t)\sin(\theta_i(t)))^2}{\Lambda_i^2}] \qquad (1)$$

Here: (x,y) is a rectangular frame of reference placed in minor cross-section, Λ_i- "tube" radius. The separate "tube" position ($\Delta_i(t)$, $\theta_i(t)$) is determined as a function of time. Numerical experiment shows that the approach could be successfully employed to describe a broad range of quite different plasma density perturbations including the axisymmetrical poloidal modes and strong turbulent perturbations. As the analytic form of the homodyne detector response is well known for the scattering from individual "tube" [3] the detector current for a set of filaments could be computed at once.

2. Quasicoherent mode simulation

Quasicoherent mode excitation has been discovered in our scattering experiment just after the transition from LH current drive regime to the fast ion generation [4]. These fluctuations are evidenced as density fluctuation bursts of well-defined frequencies being approximately the same for different K-values (see Fig.1). Such kind of spectra is only observed for narrow interval of the incident beam displacements from discharge centre towards the high magnetic field side (X= -3...-5cm). The spectral data relative to the quasicoherent mode were found in the best fit to the plasma density perturbation represented by a single rotating poloidal mode. The extremely narrow radial location of the mode δr has to be chosen in numerical run to describe the relatively shallow K-spectrum envelope. The four different parameters have been examined to fit the computed spectra to the experimental ones. Those are the radius r_0 of poloidal mode, the number of mode m, azimuth fluid velocity V_θ and δr value. The spectral peak splitting (see Fig.1) appears to be simulated by a slight temporal variation of flux surface (FS) radius δr_0 on frequencies approximating those of large scale MHD modes. The curves presented in Fig. 1 exhibit a plausible agreement between experimental and simulated data. It is worth noticing that the estimated δr magnitude turns out to be less than ion gyroradius. On the other hand, from δr value one can estimate mode parallel phase velocity exceeding a thermal electron velocity. These facts make to assume that the observed quasicoherent mode results from electron temperature drift instability. However a single harmonic excitation phenomenon needs further explanation.

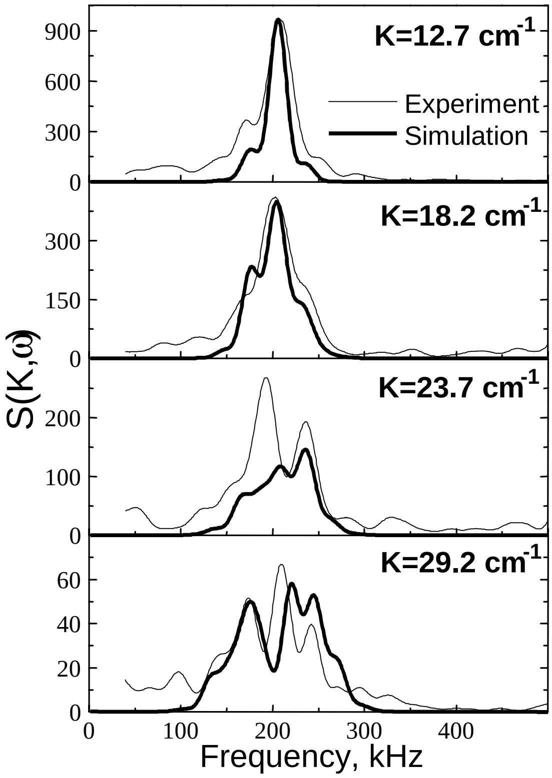

Fig. 1. Experimental and simulated spectra of quasicoherent fluctuations. $r_0 = 5.6$ cm, $m = 40$, $\delta r = 0.05$cm, $V_\theta = 1.8\cdot10^5$cm/sec, $\delta r_0 = 0.012 r_0$, $\Omega_{MHD} = 6\cdot10^3 sec^{-1}$, $M_{MHD} = 3$

3. Broad spectrum modelling

The usual broad scattering spectra are currently observed in the FT-2 tokamak OH discharges. The spectral waveforms S(ω,K) in Fig. 3 plotted in common units are the result of the ensemble averaging. The power spectra are always increased with the scattering region shift towards plasma edge. For the given scattering region displacement the S(ω,K) curves are evidently shifted to lower frequencies at low K-values. On the contrary, the high K-value spectra are approximated by the similar waveforms that is coincided with the isotropic character of microtubulence. To reproduce these mentioned features of spectra the simulation has been carried out under the two quite different assumptions. The first one is based on the plasma fluctuations presented by a set of axisymmetric poloidal modes (m_{ji}, n_{ji}) developed on rational FS. The minor radii r_i of FS are defined by $q(r_i)=m_{ji}/n_{ji}=j\cdot m_i/j\cdot n_i$ ($n_i<6$). Each poloidal mode composed of a series of Gaussian "tubes" is assumed to have a separate and random phase. The azimuth rotation of modes has been specified by well known K-depended dispersion for the drift waves [1]. The **E×B** fluid drift velocity has been taken into account as well. The model agrees reasonably along the lines of the theory of quasilinear drift wave

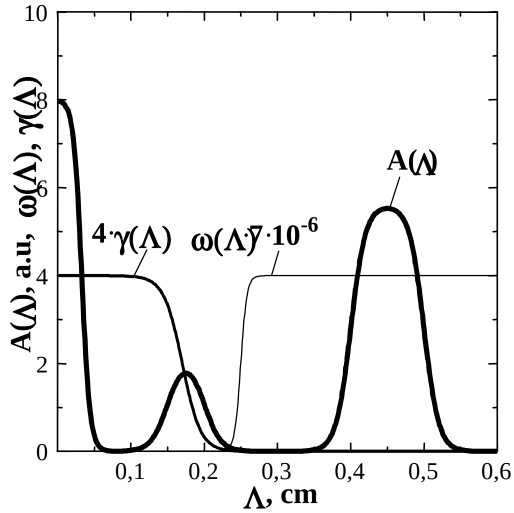

Fig. 2. Distribution functions *A(Λ), ω(Λ), γ(Λ)* for the best fit. Number of "tubes" is 10^3, r_0=6.1cm, δr=0.07 cm, δφ=0…0.4, Δt=1μsec

excitation (see for example [5]). The different kinds of functions related to mode amplitude distribution over the minor radius and K-value has been examined to fit the numerical results to the experimental scattering spectra. However, the model was found to be collapsed when tested by experiment. The most outstanding distinction relates to the multipeaked waveforms of computed spectra that could not be smoothed with including the mode short lifetime. In addition, the extremely narrow radial location ($\delta r \ll 2\pi r_i/m_{ji}$) was required for every mode to describe spectrum increasing under the plasma periphery laser probe. Such radial location is not characteristic of drift turbulence during OH regime in tokamaks.

The second proposed model is based on the substitution of real plasma fluctuations by the different scale Gaussian "tubes" executed random motion (see (1)). The limited number N of Gaussian "tubes" starting from the reference radius r_0 moves over a distance δr at random angle δφ in each time step Δt. Each "tube" was born once again at radius r_0 just after the "death" to provide the "tube" number conservation. The "tube" azimuthal rotation with angular velocity ω(Λ) has been included as well. The amplitudes of "tubes" are normalised by a function (1+γ(Λ)cosθ) to ensure the S(ω) increase under the laser probe chord shifting towards plasma edge. This procedure reflects the enhanced microturbulence due to ballooning effect known from the theory of drift instability in tokamak. The chosen distribution function ω(Λ) and γ(Λ) over radius Λ are shown

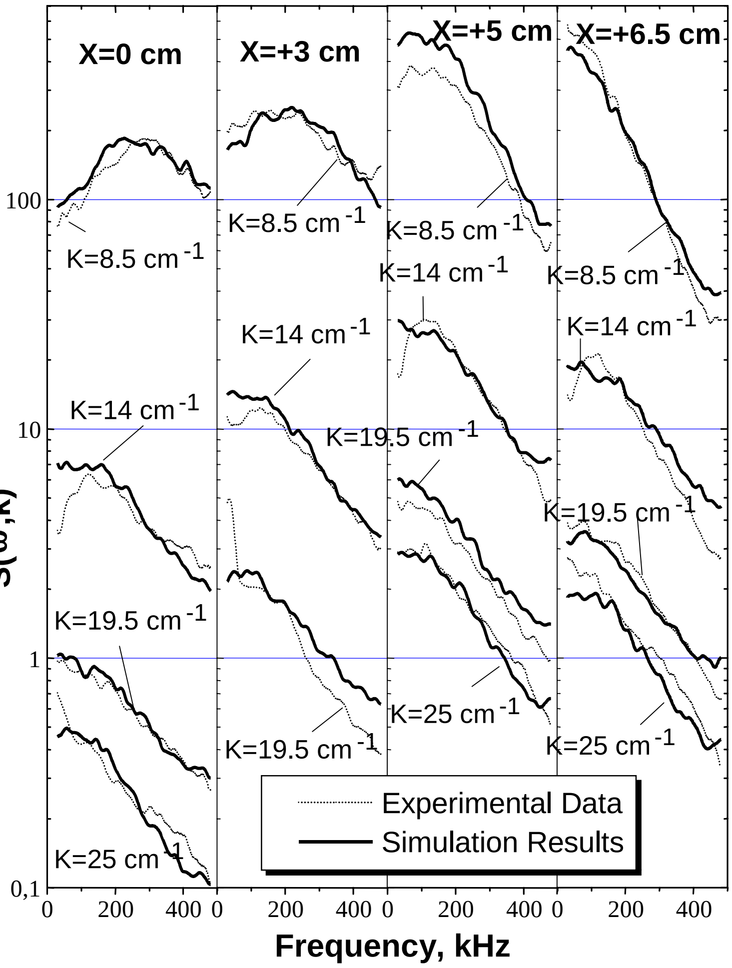

Fig. 3. Comparison of the experimental and simulated spectra for the FT-2 tokamak OH discharge (I_p=30kA, B_t=2T)

in Fig. 2. The global structure of this model is consistent with the turbulent eddy pattern predicted theoretically. The parameters N, r_0, δr have been fitted at the first simulation step to be treated afterwards as the constants. The functions $\omega(\Lambda)$, $\gamma(\Lambda)$ and the amplitude distribution function $A(\Lambda)$ defined parametric-ally have been fitted to experimental data. It is important to note that there is no way to restore experimental spectra on a basis of monotonic function $A(\Lambda)$. The function of amplitude distribution $A(\Lambda)$ presented by three kinds of "tubes" of different dimensions has been required for the best fitting (See Fig.2). The experimental together with simulation data are shown in Fig. 3 for comparison. The satisfactory agreement between them is clearly seen over the four orders of magnitude variation. The relevant scattering power K-spectra are compared in Fig. 4 as well.

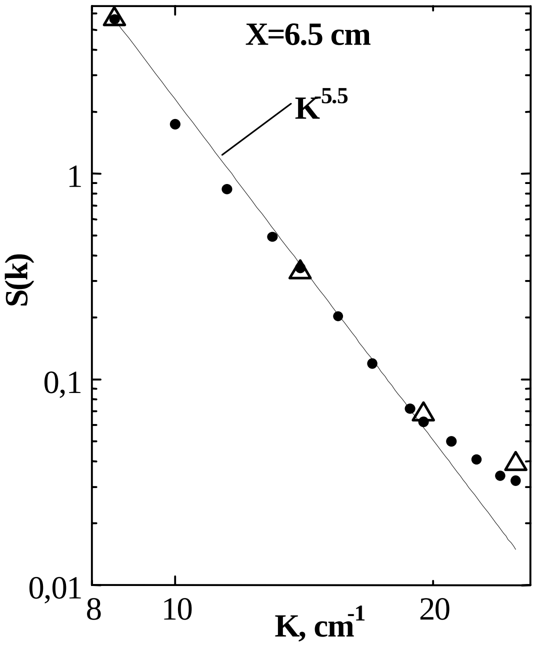

Fig. 4. Experimental (∆) and computed (•) K-spectra for the conditions mentioned in Fig. 3

4. Conclusion

It is safe to say that the representation of plasma fluctuations by superposition of Gaussian shaped "tubes" is very nice for mapping of different plasma perturbation patterns. This one is useful for the fast computing of the scattering spectra to be compared with far-forward laser scattering data. The method makes evident the structure of plasma fluctuation mode causing the quasicoherent scattering signal detected in the experiment. The simulation of the broad spectra shows that the model of axisymmetric poloidal mode excitation is collapsed when compared with measurements. On the other hand the modelling based on stochastically moved eddies provides a good agreements with the spectra obtained experimentally

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References

[1] M.Nagatsu and T. Tsukishima: Nuclear Fusion **27**, 997 (1987)

[2] V.V. Bulanin, A.V. Petrov and A.V. Vers: Plasma Physics Reports **24**, 191 (1998)

[3] D.C. Schram, H.W.H. van Andel et al.: Plasma Physics **25**, 1133 (1983)

[4] V.N. Budnikov, V.V. Bulanin et al.: *Proc. of International Workshop, Strong Microwaves in plasmas*, Nizhny Novgorod, Vol.1, 243, (1997)

[5] B.A. Carreras, K. Sidikman et al: Phys. Fluids B **4**, 3115 (1992)