Collective scattering of gyrotron second harmonic radiation during ECRH for shortwave turbulence research in the L-2M stellarator

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Experiments in collective scattering of gyrotron second harmonic radiation were carried out at L-2M stellarator. Major radius of the L-2M R_0 =100 cm and minor radius r_0 = 11.5 cm. In the L-2M magnetic field B = 1.3 T at the vacuum vessel axis is routinely used. Rotational transformation angles at the magnetic axis and at the last closed flux surface are $\acute{\imath}(0)/2\pi = 0.18$ and $\acute{\imath}(r_0)/2\pi = 0.78$ respectively.

In the paper will be discussed an application of the diagnostic which utilizes gyrotron second harmonic radiation ($k_0 \approx 30$ cm^{-1}) scattering by plasma density fluctuations. The objective is to determine shortwave turbulence parameters at different confinement conditions. Shortwave turbulence is considered as a possible explanation of anomalous transport in the L-2M [1] since both ETG and ITG modes stability criteria are exceeded at least in the central region of plasma column $r/a \leq 0.9$.

If one would compare the diagnostic with other diagnostics [2,3] based on microwave scattering technique one should note the employment of gyrotron second harmonic which is presented in a gyrotron spectrum. Radiation power at second harmonic is considered to be $10^{-5}...10^{-4}$ from total gyrotron radiation power. In our previous works it was found that second harmonic beam is well focused by ECRH quasioptical transmission line mirrors (i.e. mirrors for gyrotron operating frequency f =75 GHz). According to calculations the beam has width 2 cm and gaussian form. Polarization of the beam is founded to be same as ECRH radiation polarization. It should be mentioned that ECRH for L-2M imply heating by extraordinary wave (X-wave) at the second harmonic of electrons gyrofrequency.

In the diagnostic installed at the L-2M an upper diagnostic port is used for scattered radiation detection (see Fig.1). A special construction was installed above the port and all diagnostic elements were placed on it: PTFE lens, receiving horn antenna, collimator with microwave absorber (works like corrugated waveguide with absorbing walls), rectangle waveguide section (1.6×0.8 mm cross section, 25 mm length) with cut-off for ECRH operating frequency, microwave detector. The horn antenna was aligned to detect scattering at the angle θ = 68°. At this angle the probing-scattered beams intersection is 6...7 cm away from vacuum vessel axis and wavenumber of density fluctuations on which scattering takes place k_s = 35 cm^{-1}. Distance from scattering region to receiving horn antenna L_0 = 67 cm. Homodyne detection was chosen as a detection technique. Part of second harmonic beam was derived from the main beam and transported to receiving horn antenna. Fabry-Perot filter consisting of two thin mica (muscovite) plates was used as a coupler. The filter should provide maximum transmittance for ECRH operating frequency and sufficient reflectivity for second harmonic.

In the experiments we carried out electron temperature in the core $T_e(0)$ = 0.6...1 keV, magnetic field at the vacuum vessel axis B = 1.3 T. Electron temperature profile had bell shape with maximum at the vacuum vessel axis, i.e. shifted outward vacuum magnetic axis about 2 cm (Shafranov shift). Electron temperature had a 100...200 eV slump near the last closed flux surface. Plasma density was $n_e(0) = 1.5...1.7 \cdot 10^{13}$ cm^{-3}, density profiles was flat. ECRH pulse length was 10...15 ms. Confinement conditions which were intentionally varied: 1) ECRH power (100...200 kW); 2) boundary conditions at the plasma periphery which were changed by inserting a limiter into the plasma column (limiter width 8 cm, its edge repeats last closed flux surface shape); 3) magnetic axis position shift which can be performed with vertical magnetic field B_v (B_v = – 20 G corresponds to inward shift $\approx$ 2 cm).

Fig.2 shows features of scattering signal from the described diagnostic. The gyrotron starts in the 46 ms and the reference signal arise (it seems that first spike corresponds to transient process at generation mode establishing in the gyrotron). Gas breakdown takes place in the 47.5 ms and plasma arises. Then a fast density increase occurs and it results in large amplitude fluctuations in the scattering signal. For a turbulence characteristics description should be used signal from 51 ms since plasma is at quasi-steady state. It should be noted that received signal contains a fast-oscillating component (corresponding to interference between reference signal and scattering) and a quasi-constant component. One can make a conclusion about presence of the quasi-constant component from existence of a strong low frequency (0.5...1 kHz) signal modulation. One can clearly see this modulation by averaging signal over 300 μs. Such waveform determined by interference of three signals: reference signal, signal scattered by density fluctuations and signal scattered by constructional elements within vacuum vessel which should considered as a stray radiation. Quasi-constant signal phase changes with density variation in time which leads to slow modulation of the total signal.

With minimum values $U_{\min}$ and maximum values $U_{\max}$ of the averaged signal can be calculated reference signal level $a^2 = 0.25(U^{1/2}_{\max} + U^{1/2}_{\min})^2$ and quasi-constant component level $c^2 = 0.25(U^{1/2}_{\max} - U^{1/2}_{\min})^2$. The fast-oscillating signal $U_{\sim}$ is obtained by subtraction of the averaged signal from the total signal. Then density fluctuations energy values is calculated as $n_{\sim}^2 = U_{\sim}^2/a^2U_{\max}$. This estimation was made for each discharge in series (usually dozen of discharges in series) with investigating confinement conditions (see above). Then mean values and standard deviations for series were calculated. The results are presented in the table. Each row in the table corresponds to a specific confinement conditions (see columns 2-4).

Table

Label	**P_{ECRH}, kW**	**Limiter insertion, cm**	**B_v, G**	**Discharge in series**	**$\langle n_{\sim}^2 \rangle$, 10^{-3} r.u.**	**c^2/a^2**	**τ_E, ms**
a)	90	0	0	10	0.7±0.1	0.02	4.4±0.2
b)	90	2	0	14	3.8±0.3	0.07	3.2±0.1
c)	160	0	0	11	1.4±0.5	0.04	2.3±0.3
d)	170	2	0	16	3.4±1.7	0.06	1.9±0.2
e)	150	0	-20	9	1.4±0.5	0.02	2.9±0.1
f)	140	2	-20	16	4.8±1.7	0.03	2.4±0.1

Table shows that ECRH power increase from 90 kW to 160 kw leads to fluctuations energy increase up to two times and energy confinement time τ_E decrease from 4.4 ms to 2.3 ms. This indicate a possible correlation between shortwave density fluctuations energy increase and energy confinement time decrease with ECRH power increasing. Inward magnetic axis shift (limiter isn't inserted) leads to 1/4 energy confinement time increase however fluctuations energy isn't affected (at least within measurement errors). Limiter insertion causes sharp increase in fluctuations energy at the same time energy confinement time decreases but no more than by 1/4.

For each discharge in series with specific confinement conditions (see table) scattering signal spectrum was calculated (using Welch algorithm for 9 time windows 1 ms length each) and then spectra were averaged within series. The averaged spectra were normalized to the fluctuations energy value from the table. Fig.3 shows averaged spectra (one time window 1 ms length) for each confinement condition represented in table rows a,b,c,d,e,f. Spectra features are concentration of substantial energy part in narrow band up to 25 kHz and presence of one or two spectral peaks (10-20 kHz width) in 0…50 kHz band.

The diagnostic based on collective scattering of heating gyrotron second harmonic radiation by plasma density fluctuations confirmed its right to exist as a reliable instrument for shortwave turbulence investigation. For this diagnostic experimental confirmation of second harmonic beam parameters (power, polarization, power distribution, width etc.) are advisable but not vital. It was found that for the diagnostic there was no need for stray radiation absorption and signal-to-noise ratio was sufficient. Averaged shortwave fluctuations energy and spectra were obtained for each investigating confinement condition. Obtained results are essential material for further determination of instabilities growth of which results in shortwave turbulence in L-2M stellarator.

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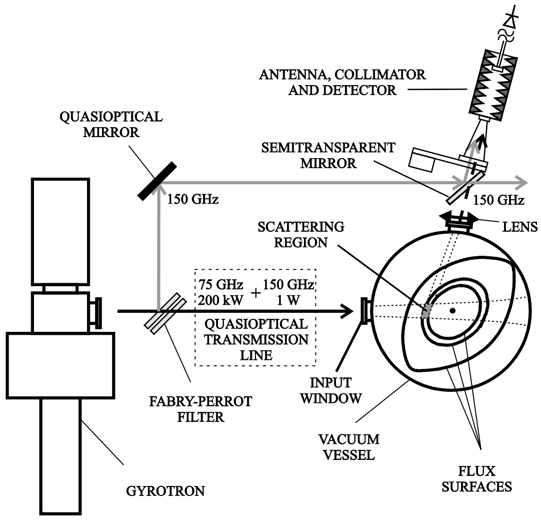

Fig.1. Diagnostic setup

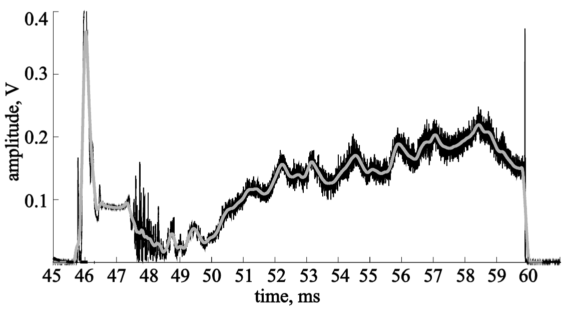

Fig.2. Scattering signal

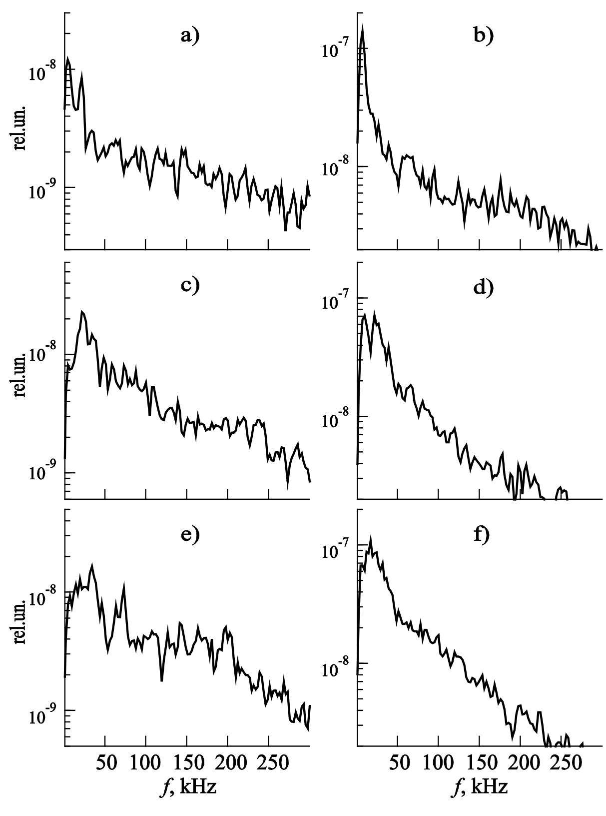

Fig.3. Scattering spectra (a,b,c,d,e,f corresponds to rows labels in table)

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