SPECTRUM BROADENING OF LHW LAUNCHED IN TOKAMAK CASTOR BY MULTIJUNCTION GRILL ANTENNA

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1. Introduction

Recently, measurements of low power lower hybrid waves (LHW) launched by quasioptical grills (f=9.3 GHz) into the CASTOR tokamak plasma were performed [1]. Strong fluctuations of LHW amplitude and phase, hindering the determination of the wave $N_{\|}$ have been observed. The question arose: are these fluctuations specific for the quasioptical grills or they accompany LHW launched by other types of grills, too? And, moreover, do these fluctuations correspond to the well known LHW spectrum broadening? We attempted to answer these questions by repeating the experiments, but with a formerly used multijunction grill working at the frequency f=1.25 GHz and power up to 50 kW, sufficient for a substantial current drive.

2. Experimental arrangement

Ray tracing of LHW propagating at frequency 1.25 GHz along the plasma column in tokamak CASTOR is shown in Fig. 1a) (z denotes the vertical coordinate, see Fig. 1b) for a parabolic density distribution with maximum central value $n(0) = 7 \times 10^{18}$ m^{-3}.

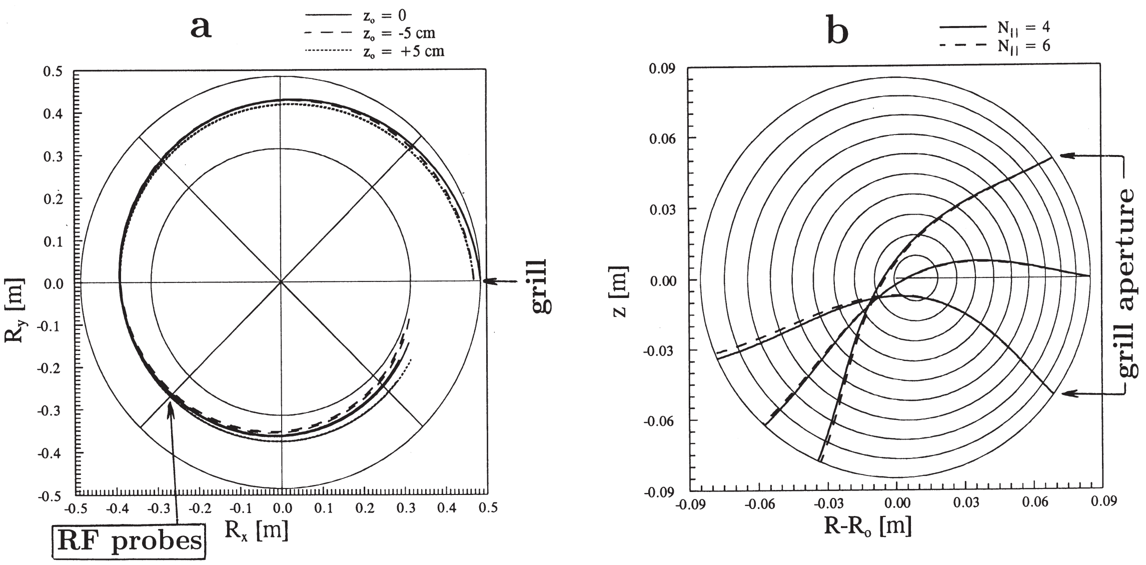

Fig. 1. Ray tracing of LHW with f = 1.25 GHz launched near CASTOR equatorial plane for a parabolic density distribution with $n(0)$ = 7 $\times$ 10^{18} m^{-3}; a - top view, b - poloidal cross-section.

The launching antenna is placed in the outer horizontal port and it has poloidal width about 60^o, see right side of the Fig. 1b. Traces of three rays coming from different points of the grill aperture are depicted. For the measurements of the LHW $N_{\|}$ spectrum, an RF coaxial double probe detecting squares of the wave amplitudes, P_1 and P_2, at two points separated 6 mm toroidally and placed in a poloidal cross-section 135^o toroidally away from the grill antenna has been used. The probe enters the plasma through a lower port and it is movable through the whole poloidal cross-section of the device.

A coaxial RF circuit for determination of the wave phase velocity (i.e. the mutual phase φ of the wave at these two points) has been developed and realized, see Fig. 2. All detectors P_1, P_2 and P_{ph} (phase detector) shown in Fig. 2 are absolutely calibrated in the whole range of power used.

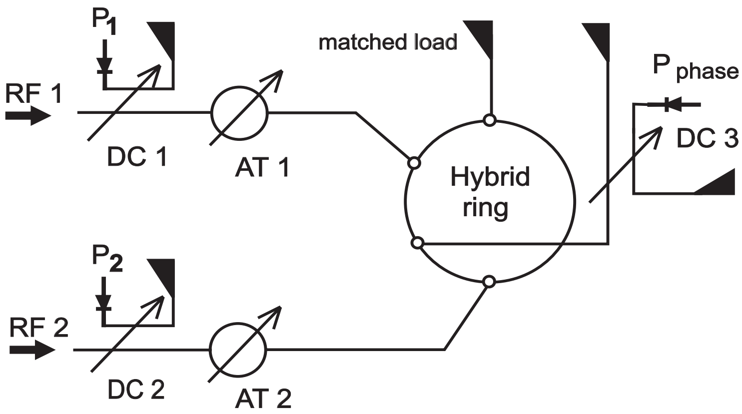

Fig. 2. RF coaxial circuit for detection of the LHW phase velocity.

As launcher, a 3-waveguide multijunction grill with a relatively broad spectrum $N_{\|}\epsilon < 1; 5 >$ has been used. The power of the RF generator used (several tens of kW) is comparable with the ohmic heating power and about 60% of the total electric current is driven under these conditions in CASTOR.

3. Experimental results

The method of the LHW phase measurements used is described elsewhere [2]. The scheme shown in Fig. 2 makes us possible to measure, in addition to the squares of electric field intensities at the two points, P_1 and P_2, also the square of interference signal P_{ph} of the both fields (depending on their phase difference). Results of the measurement are shown in Fig. 3 in the long time scale (together with loop voltage U_{loop} and line averaged density n, see left side of the figure) as well as in the short time scale (sampling rate 0.5μs, see right side of the figure). Following conclusions can be drawn from this figure:

1. General feature of all measurements is a strong fluctuating modulation of these amplitudes in time (and as well as in space, see e.g. [2]).

2. Phase difference φ of the waves detected using the RF double probe (i.e. $N_{\|}$) strongly fluctuates as well (in an interval <10;90^o>), however, it is measurable in this case of relatively long wavelength used (λ = 24 cm, instead of 3 cm used in [2]).

3. A considerable broadening of the antenna $N_{\|}$ spectrum into the region of short wavelengths (up to $N_{\|} \doteq 10$ can be deduced from the fact given in the foregoing point and from the distance of two probe tips.

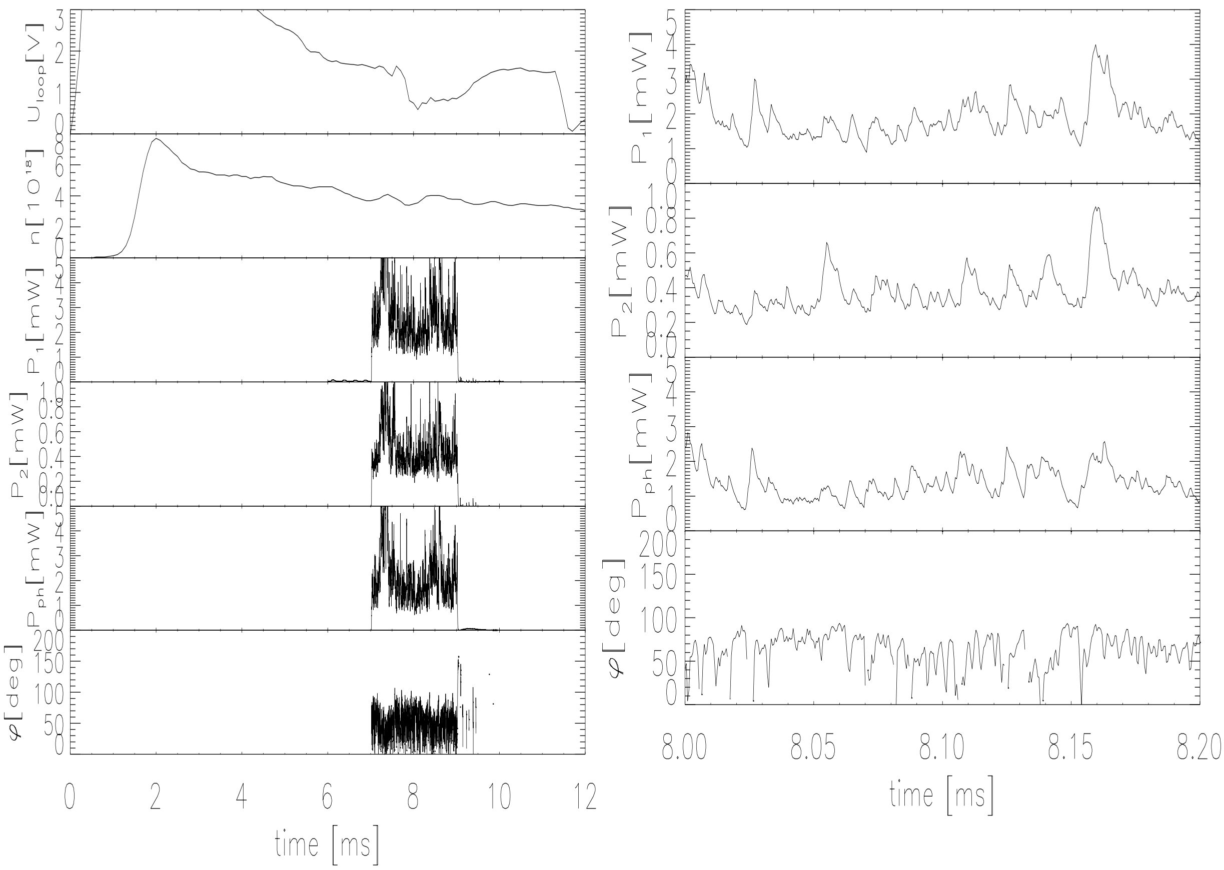

Fig. 3. Phase evaluation of LHW launched in CASTOR by 3-waveguide multijunction grill (shot # 5581, probes on the radial position $r = R - R_o$ = -60 mm, z = 0).

Further, it has been found:

1. Amplitudes of the signals from the RF double probe increase from the edge towards the center of the plasma in concordance with the LH cone existence.

2. The level of LHW fluctuating modulation doesn't depend on the probe position.

4. Remarks on the interpretation of the measurements

We use the commonly accepted hypothesis about the LHW spectrum broadening to slow phase velocities $\omega/k_{\parallel} \simeq$ (3-4)v_{Te}. For CASTOR tokamak plasma, the corresponding spectral width is $\Delta k_{\parallel} \geq k_1 =$ the minimal $k_{\parallel}$ of the launched spectrum. Therefore, in the region of the RF probe, the LHW field acquires the form of wave packets with lengths $\approx 2\,\pi/\Delta k_{\parallel}$. These wave packets arise as an interference of waves coming from different parts of the grill and penetrating regions with different plasma density fluctuations.

In the case of the former 9.3 GHz quasi-optical grill with the peak of the spectrum at $N_{\parallel} = k_{\parallel}c/\omega \simeq 3$, the length of the wave packets is $\leq$ 1 cm. Comparing it with the RF probe tips mutual distance 6 mm, we can understand why practically no correlation of the two probe signals has been found.

For the 1.25 GHz multijunction grill, the above (3-4)v_{Te} limit implies that the maximal value of $N_{\parallel} \simeq 10$ can be expected. The length of the corresponding shortest wave packets

$\approx$ 24cm/10 is four times larger than the RF probe distance, a fact improving considerably the conditions for the phase measurements mentioned above. This expectations are in accordance with the experimental results, where

(i) the phase measurements with the 1.25 GHz grill are possible and

(ii) the maximum phase difference of the waves detected by the two RF probes is 90^o, corresponding to $N_{\|} \simeq$ 10.

Due to the plasma fluctuations along a wave path mentioned above, the wave phase includes a fluctuating part $\psi \simeq 2\pi m\kappa(t)/k_{\|}$, where m is the number of the wavelengths $2\pi/k_{\|}$ along the wave path and κ is a part of $k_{\|}$ which varies due to the δn fluctuations. Assuming that $\psi > 2\pi$, we obtain the following relation for frequencies f_ψ and f_n of ψ and of δn fluctuations, respectively:

$$f_\psi \approx 4\pi m\kappa_{max} f_n/k_{\|}.$$

Therefore, the interference patterns of the LHW in the RF probe region fluctuate with the characteristic frequency f_ψ. The values of m and $\kappa_{max}/k_{\|}$ may vary in broad limits. As an example, we take m = 20, $\kappa_{max}/k_{\|}$ = 0.05 and obtain $f_\psi \approx$ 10 f_n, a value corresponding to the experimental results.

5. Conclusion

Detailed measurements of the local density fluctuations in the place of RF probes as well as in front of the launching antenna [1], made on CASTOR at a low level of RF power at the frequency f=9.3 GHz, don't reveal any correlation with analogical LHW fluctuations observed in that case. Theoretical estimates show that such complex picture can be explained as an integrated effect of density fluctuations along the whole waves rays from the antenna to the point of measurements.

As to the two questions formulated above, we conclude that (i) the LHW amplitudes and phases fluctuations are not specific for the quasioptical grills, (ii) these fluctuations approximately correspond to spectrum broadening expected; in other words, spectral gap filling to the phase velocities (3-4)v_{Te} has been confirmed by means of direct wave measurements.

Acknowledgement

This work has been supported by the grants of GA CR 202/97/0778 and 202/96/1355.

References

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