PECULIARITIES OF THE RADIOMETRIC MEASUREMENTS ON URAGAN-3M TORSATRON FOR RF HEATED PLASMA

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Frequency spectrum (radial profile) of X-mode second harmonic electron cyclotron emission was observed for optically thin plasma produced by Alfvén resonance heating in Uragan-3M torsatron. Radial electron temperature profile within frequency range 31.5–37.5GHz is covered a significant portion of the plasma column radius. Temperature profile derived from "radiation temperature" profile. This procedure neglects multiple reflections of ECE radiation from the torsatron inner structure (mainly from helical coils). We relate the mismatch effect of the ECE radiation data by the strong modification of emission level by plasma opacity (small plasma optical depth) and by the scrambling effect. This effect results from both O-X mode conversion. Electron temperature is calculated from radiation temperature using tokamak approximation for the optical thickness. The difference in ECE and other data is explained using some modification of electron density profile.
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INTRODUCTION

Uragan-3M (U-3M) torsatron is a medium size device with l = 3, m = 9, major radius R_0 = 1m, average plasma radius $\langle a_{pl}\rangle$ = 0.12 m and toroidal magnetic field B_t<1T. Electron cyclotron emission (ECE) near the electron gyrofrequency and its harmonics is routinely used for electron temperature measurements in U-3M plasma experiments. The advantage of this method is that in an inhomogeneous magnetic field, the region of emission is very close to the resonance points and a local value of the temperature is obtained with good spatial resolution. A single spatial channel conventional radiometer is used for detection of the electron cyclotron emission from the U-3M plasma. The U-3M plasma built-up followed by is made by RF power (up to 150 kW) at 8.6, 8.9 MHz that corresponds to ~ $0.8\omega_{ci}$ at 0.7 T. The experiments are carried out under $(0.5...3)\times10^{12}$ cm^{-3} of the mean plasma density and 0.1...1 keV of the central electron temperature.

ECE RADIOMETER SET-UP AND EXPERIMENTAL RESULTS

ECE system utilized multi-frequency one channel heterodyne radiometer. Based on U-3M plasma parameters, second harmonic X-mode is chosen as operation mode. Radiation from the plasma is collected by a conical horn antenna (Fig. 1), with a nominal 20 dB of gain at the axis and after a 10 meters oversized X- and Ka-bands waveguide line it applies to a broadband balanced receiver system. Antenna has a circle-to-rectangular transition section which chooses the receiving polarization of radiation. Radiometer is equipped with 1.5 eV signal calibration unit. Signal of which is routinely compared with plasma one.

Usually for the thermonuclear plasmas the relevant frequency and temperature range for ECE measurements the classic approximation $\hbar\omega \ll k_B T_e$ ($\hbar$ and k_B are Planck and Boltzmann constant) is valid,

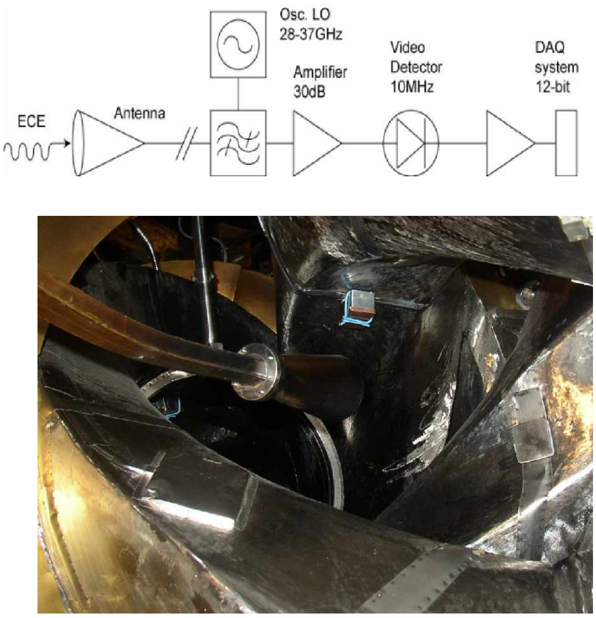

Fig. 1. Block diagram of U-3M ECE radiometer (top) and antenna system (bottom)

so the Rayleigh-Jeans law can be used to calculate radiative emission. In the well known [1] traditional form (black body intensity of radiation) it is:

$$I_{BB} = \omega^2 \frac{k_B}{8\pi^2 c^2} T_e. \quad (1)$$

If we consider the propagation of the radiation through the plasma the detected (coming into antenna and detection system) part will be governed by the:

$$I = I_{BB}\left(1 - e^{-\tau}\right), \quad (2)$$

where, $\tau = \int \alpha dr = f(T_e, n_e)$ – plasma optical depth, α is the plasma absorption coefficient. In optically thick plasmas, ($\tau > 3-4$) the intensity of the ECE radiation (so called radiation temperature T_{rad}) is proportional to the local electron temperature T_e. Thus, information regarding the local plasma electron temperature and its fluctuations can be obtained by measuring the intensity of optically thick ECE harmonics (direct measurement).

$$T_e = \frac{T_{rad}}{\left(1-e^{-\tau}\right)}, \qquad (3)$$

following [2,3] for the case U-3M plasmas the optical depth varied from 0.5 to 1.8, thus, this is a case of optically thin plasma (“grey plasma”) and simple correction for the real temperature must be done. Numerically plasma optical depth (using tokamak approximation) could be expressed as:

$$\tau \approx 3.7\times10^{-14} < n_e > T_{rad}(R)R/B_0, \qquad (4)$$

here the plasma density is in cm^{-3}, electron temperature is in keV, tore major radius R is in cm, and the magnetic field is in kG.

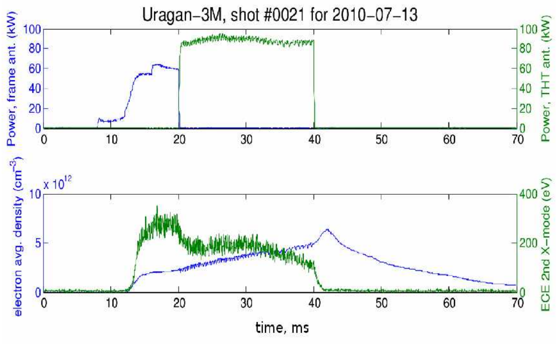

Fig. 2. Temporal evolution of the injected power of the both RF antennae (top) and electron average density radiative temperature (bottom)

Under similar plasma conditions T_e radial profile could be obtained if we combine data from several consecutive plasma discharges only. During the chosen operational regime ECE system receiving frequency was changed from shot to shot from 30 to 37 GHz. One of typical shots is shown at the Fig. 2. Then those time series of ECE signals were converted into corresponding plasma temperature [3]. 2-D contour plot of the temporal evolution of the electron temperature profile is shown in the Fig. 3. One can see that at the plasma center (R_{ax}=105.25 cm) region outward shift of the temperature maximum. Additional 'local' temperature peak was found around the magnetic islands chain (R=108.8 cm). For the case of the “grey plasma” the values of the local plasma temperature strongly depends on the knowledge of the local plasma density. In the absence of direct measurements of the plasma profile by the means of Thomson scattering or multi-frequency interferometry electron density profile was deducted from single chord interferometry for the plasma core and edge probe measurements.

Comparison of local plasma pressure (electron root) with net plasma pressure obtained from the diamagnetic measurements is presented in the Fig. 4.

Estimation of the plasma confinement time was done for the moment of heating power switching off. One can use approximate formula:

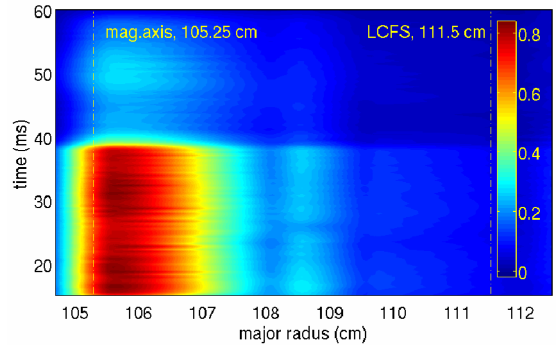

Fig. 3. 2-D Temporal evolution of the electron temperature profile (colored levels of temperature are in the keV)

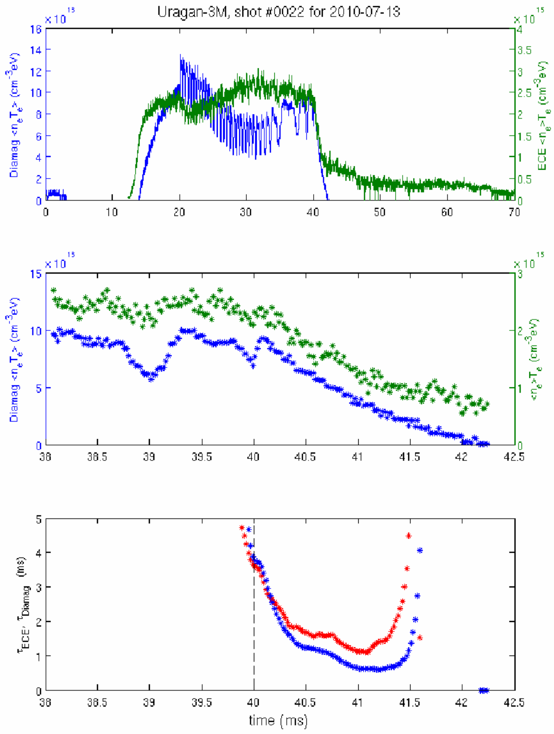

Fig. 4. Temporal evolution of the plasma pressure from local ECE and net diamagnetic measurements (top) their “zoomed” parts for the time of RF heating switch-off (middle) and corresponding energy confinement times

$$\frac{dW}{dt} = \frac{-n_e T_e V}{\tau_E} + W_{RF}, \qquad (5)$$

in the absence of the heating term (P_{RF}) energy confinement time τ_E could be evaluated. Its value (at exact time of switching off of the RF power (W_{RF}=0) – 40.1 ms) has very good agreement with that which have been derived from the data of diamagnetic diagnostic.

CONCLUSIONS

ECE heterodyne radiometer system was routinely used for plasma temperature evaluation during plasma experiments at U-3M torsatron.

Electron temperature is calculated from radiation temperature using tokamak approximation for the optical thickness. The difference in ECE and other data is explained using some modification of electron density profile. For special plasma production conditions (additional gas-puffing) an ECE "cut-off" phenomena (rapid signal losses) due to the overdense plasma is observed. That is why for low dense low temperature case higher frequency range is needed for ECE measurements. For this purpose new six channel ECE superheterodyne radiometer system is under installation now. It optimized for the 1T magnetic field operation and has a frequency range 57…74GHz.

We relate the mismatch effect between real electron temperature and those from ECE radiation data by the strong modification of emission level caused by the plasma opacity (small plasma optical depth) and by the radiation scrambling effect.

ACKNOWLEDGEMENT

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ОСОБЕННОСТИ РАДИОМЕТРИЧЕСКИХ ИЗМЕРЕНИЙ НА ТОРСАТРОНЕ УРАГАН-3М ПРИ ВЧ-НАГРЕВЕ ПЛАЗМЫ

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Радиальный профиль электронно-циклотронного излучения второй гармоники с необыкновенной поляризацией для оптически тонкой плазмы был получен во время экспериментов по созданию и нагреву плазмы на торсатроне УРАГАН-3М в области частот, близких к альфвеновскому резонансу. Соответствующий радиальный профиль электронной температуры в частотном диапазоне 31.5…37.5 ГГц покрывает значительную часть плазменного шнура. Различие между радиационной и истинной температурами обусловлено малыми значениями плазменной оптической толщины из-за небольших значений плотности плазмы. Различия в полученных данных ЭЦР-излучения можно отнести за счет изменения уровня прозрачности плазмы (малые величины оптической толщины) и за счет эффекта перемешивания поляризации излучения. Температура электронов вычисляется из температуры излучения, используя приближение токамака для оптической толщины. Разница полученной температуры по данным ЭЦР по сравнению с другими диагностиками может быть объяснена как следствие некоторой локальной модификации электронного профиля плотности.

ОСОБЛИВОСТІ РАДІОМЕТРИЧНИХ ВИМІРЮВАНЬ НА ТОРСАТРОНІ УРАГАН-3М ПРИ ВЧ-НАГРІВІ ПЛАЗМИ

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Радіальний профіль електронно-циклотронного випромінювання другої гармоніки з незвичайною поляризацією для оптично тонкої плазми був отриманий під час експериментів зі створення та нагріву плазми на торсатроні УРАГАН-3М в області частот, близьких до альфвенівського резонансу. Відповідний радіальний профіль електронної температури в частотному діапазоні 31.5…37.5 ГГц покриває значну частину плазмового шнура. Різниця між радіаційною і справжньої температурами обумовлена малими значеннями плазмової оптичної товщини через невеликі значення густини плазми. Відмінності в отриманих даних ЕЦР-випромінювання можна віднести за рахунок зміни рівня прозорості плазми (малі величини оптичної товщини) і за рахунок ефекту перемішування поляризації випромінювання. Температура електронів обчислюється із температури випромінювання, використовуючи наближення токамака для оптичної товщини. Різниця отриманої температури за даними ЕЦР в порівнянні з іншими діагностиками може бути пояснена як наслідок деякої локальної модифікації електронного профілю густини.