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RADIAL DISTRIBUTIONS OF RF DISCHARGE PLASMA PARAMETERS AND RADIAL ELECTRIC FIELD IN THE URAGAN-3M TORSATRON

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The results of local measurements of RF discharge plasma parameters (plasma density and its fluctuations, electron temperature and energy of superthermal electrons, plasma poloidal rotation velocity) in the Uragam-3M torsatron are presented. The obtained data are analyzed taking into account the peculiarities of the Uragan-3M magnetic configuration and scenario of RF plasma production and heating. Some suppositions about mechanisms of a radial electric field generation are discussed with the calculation of a magnetic configuration island structure.

1. Introduction

It has been demonstrated in a variety of toroidal devices that E_r x B velocity shear is a key mechanism which can explain the reduction of plasma turbulence and the formation of transport barriers leading to improvement of plasma confinement. In accordance with the theory radial electric field can be determined from the equation:

$$E_r = \frac{1}{n_i Z_i e}\nabla P_i - V_\theta B_o + V_{//} B_\theta ,$$

where n_i is the ion density, P_i is the ion pressure, $Z_i e$ and *e* are the charges of the ion and electron, V_θ and $V_{//}$ are the poloidal and toroidal rotation velocities, and B_θ and B_o are the poloidal and toroidal magnetic fields.

It is necessary to note that plasma rotation velocities can be conditioned by a power deposition profile in the plasma column, the ion-electron flux difference in the vicinity of rational magnetic surfaces and presence of fast particles generated in the process of plasma heating. In connection with this the study of profile effects has the very important meaning for the explanation of radial electric field generation. The case of the presence of island chains of low order resonant surfaces in a magnetic configuration with small shear with sufficient heating power in the region of their localization is most interesting for the study in accordance with the point of view which the theory develops now.

2. Experimental arrangement

Experiments were carried out on the Uragan-3M torsatron with open helical divertor (l=3, m=9, R_o=100cm, $\overline{a}_{pl}$=12,6 cm) at the magnetic field strength B_o=0,72 T.

The measurements made by the triode and luminescent techniques have shown that there is the possibility to realize the magnetic configuration with two chains of islands, which are located in the region of small shear [1]. Such a configuration takes place at the ratio of vertical magnetic field to longitudinal one $B_\perp/B_o$~1,25%. The outside shift of the magnetic axis from the geometrical axis of helical coils is equal to 5,5cm in this case (Fig.1).

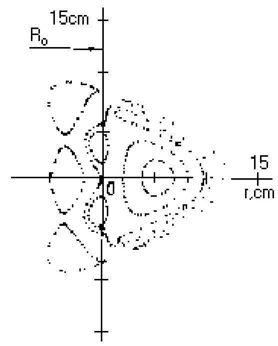

Fig. 1. The magnetic island structure of the Uragan-3M torsatron at $B_\perp/B_o$~1,25%

The frame type antenna was used for RF plasma production and heating to provide a sufficient heating power in the region of island chains localization. Numerical simulations has shown that the waves with long wavelength excited by this antenna are absorbed at the external part of a plasma column, $\overline{r}/a$ >0,5, where island chains are located (Fig.2).

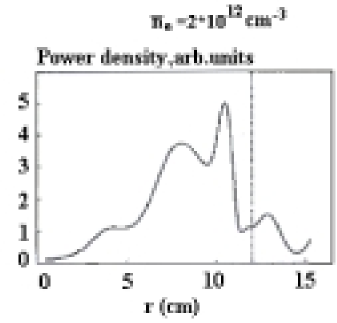

Fig.2. The power deposition profile for the frame type antenna

Radial distributions of plasma density and its fluctuations (multichord interferometry and reflectometry), electron temperature (ECE diagnostics and laser scattering) and plasma poloidal rotation velocity (poloidal correlation reflectometry) have been measured. The energy spectra of charge exchange neutrals were measured in tangential and perpendicular directions to the toroidal plane by neutral particle analysers. Some data were obtained by means of probe and electrotechnical measurements.

3. Experimental results

The experiments were carried out in the range of plasma densities $2.10^{12}<n_e<5.10^{12}$ cm^{-3} to provide the power deposition profile shown in Fig. 2.

The spectrum of electron cyclotron emission in the frequency range from the first to the second harmonic was measured by three heterodine radiometers with spectral resolution $\nabla\omega/2\omega_{ce}$~0,038% and threshold sensitivity ~0,5 eV. The spectrum of emission (Fig.3) at $\omega=2\omega_{ce}$ is clouse to

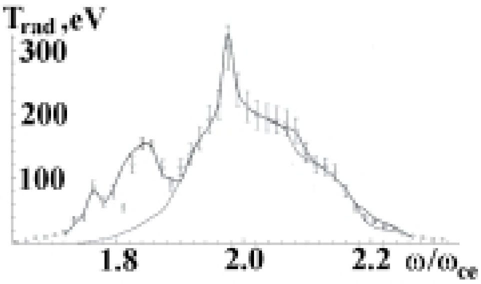

Fig.3.The spectrum of ECE

the thermal one, but it has peculiarities in the long-wavelength region $\omega/\omega_{ce}<1,85$ and in the short-wavelength region in the vicinity of frequencies $\omega\approx 2,02\omega_{ce}$ and $\omega\approx 2,1\omega_{ce}$. The maximum of the emission is observed at $|B/B_o|=0,96$ that is on the axis of the magnetic configuration. It is easy to see that the deviations of the measured spectrum from thermal one in the short-wavelength part correspond to local maxima of electron temperature in magnetic islands (Fig.4).

The peculiarity of the spectrum in the long-wavelength region ω/ω_{ce}~1,85 corresponds to the localization of fast electrons with energy about of 1,2 keV on the plasma edge [2].

Numerical simulation has shown that the power deposition profile provided by frame type antenna shifts to the plasma periphery with the density rise.

The energy spectra of charge exchange neutral measured in tangential and perpendicular directions to the toroidal plane show a two temperature ion distribution ($T_{i1}\approx 300$ eV, $T_{i2}\approx 800$ eV). Doppler broadening of the CV line (227,1 nm) indicates that these impurity ions are in equilibrium with the lower temperature part of the hydrogen ion distribution T_i (CV)$\approx T_{i1}$ during almost the whole RF pulse duration [3].

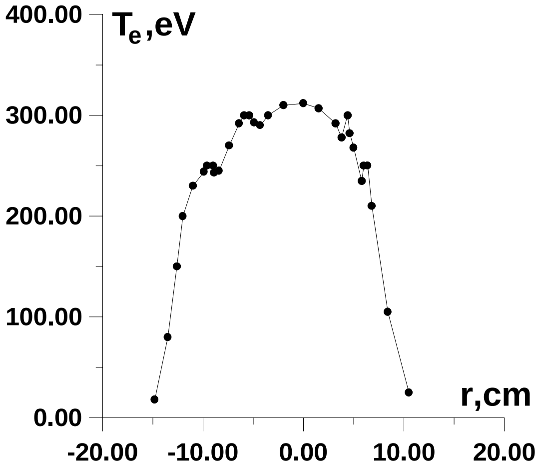

Fig. 4. The radial distribution of the electron temperature

Measurements with changing the entrance slit width of the longitudinal and perpendicular charge exchange analysers indicate that high energy ion generation takes place at the plasma edge and the region of their localization moves outside with the density rise too. It is necessary to note that these peculiarities of $T_e(r)$ and the presence of fast electrons and ions were observed during all quasistationary stage of the RF discharge and disappeared through ~150 μs after RF pulse was switched off.

It was interesting to study an asymmetry of plasma density profile and its fluctuations relative to magnetic axis determined by magnetic field configuration and the method of plasma production and heating. The microwave interferomtry (λ=2-8 mm) and reflectometry (λ=8-17 mm) were used for the density profile reconstruction. The density fluctuation level was estimated from reflected signal phase fluctuations measured by cross-detection technique. Radial profiles of wave numbers, coherency and correlation length were measured by dual-polarization radial correlation reflectometry, and at last, the poloidal rotation velocity of plasma was measured by means of poloidal correlation reflectometry.

Analysis of obtained data allowed to make the following conclusions:

-Spectra of density fluctuations observed at O-mode reflection at adjacent ($\nabla r\leq 4$ cm) plasma layers are similar and have a rather high coherency ($\gamma_{1,2}\approx 0,4$-0,6).

-The estimates of plasma density fluctuation level showed that these fluctuations are stronger at the outer part of plasma column (Fig.5).

-The tendency of increase of radial wave numbers k_r of fluctuations with radius increase was observed (Fig.5). It is interesting to note that observed maxima of k_r are located in the region of magnetic islands.

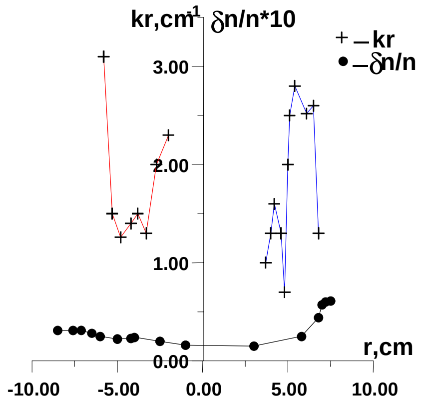

Fig.5.Radial distributions of radial wave numbers, k_r, and the plasma density fluctuation level, $\frac{\delta n}{n}$

-The high velocity shear is observed in the region of localization of island chains (Fig.6).

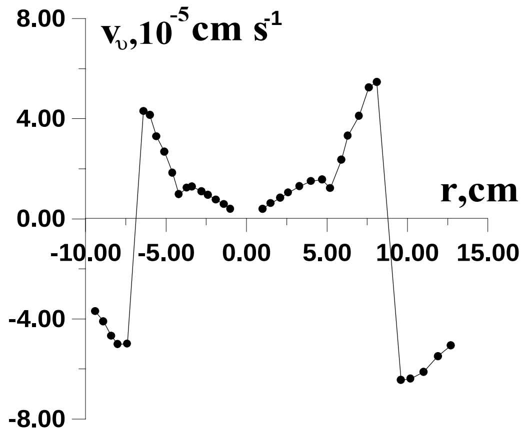

Fig. 6. The radial distribution of the poloidal rotation velocity

-The sharp decrease of the radial electric field value was observed in the layer between the chains of magnetic islands (Fig.7).

4. Conclusion

The case of the presence of island chains of low order resonant surfaces (t=1/4) in a magnetic configuration with small shear with sufficient heating power in the region of their localization was realized in the presented experiment.

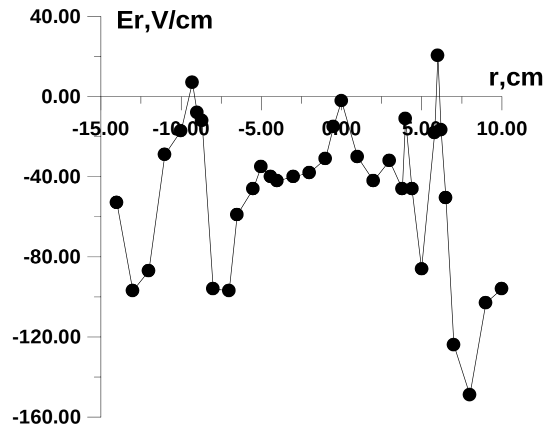

Fig. 7. The radial distribution of Er

Some pecuiarities in radial distributions of plasma parameters were observed in this case in the region of rational magnetic surfaces (high poloidal rotation velocity shear, high radial electric field shear, increase of k_r, peculiarities on distribution $T_e(r)$). It is reasonable to suppose that all these peculiarities are connected with stochastization of magnetic field lines near the island chains and the increase of electron thermoconductivity in these regions. All these effects can have very important role in the formation of an interior transport barrier.

Acknowledgements

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