

Specific features of ICR heating on the spherical tokamak Globus-M at high concentration of light ion component

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Abstract. The results of ICR heating on the spherical tokamak Globus-M are presented. The role of the 2nd cyclotron hydrogen harmonic is shown to be negative when it is located in front of the antenna. Effective ion heating takes place at concentration of light ion plasma component up to 70%.

In spherical tokamaks the conventional ICR plasma heating has a number of specific features and therefore requires additional investigations. The first and the most important point consists in simultaneous existence of several IC harmonics in the plasma cross-section, in which RF power absorption is possible with different efficiency. The other feature consists in the fact, that due to steep magnetic field gradient the width of resonance absorption layers is much smaller than excited wave length and consequently the efficiency of one-pass absorption is not high. And at last, there is an intrinsic property of the Globus-M tokamak: the amount of hydrogen in a deuterium plasma can vary in the range 10-50% in different experimental conditions. For this reason, the efficiency of cyclotron absorption can also change.

The ICRH experiments were performed on the low aspect ratio tokamak Globus-M ($R=0.36$ m, $a=0.24$ m,) at $B_0 = 0.4$ T [1]. Plasma currents in various shots differed from 150 kA up to 240 kA, axial plasma density changed from $2 \cdot 10^{19}$ m⁻³ to $5 \cdot 10^{19}$ m⁻³ and operating frequency changed in the range 7.5 MHz – 9.2 MHz. The maximum input power was about 200 kW, pulse duration was up to 20 ms. The usual single-loop antenna coated by NB ceramic was installed in the chamber port for FMS wave excitation. After the conditioning procedure, no influx of impurity ions was seen during the RF pulse. The plasma density increased to a small degree. The ion temperature behaviour was observed by a 12-channel analyzer ACORD-12, which measured simultaneously hydrogen and deuterium fluxes and relative concentration of ion components [2]. The line of observation was perpendicular to the plasma boundary, in the equatorial plane of the installation. The electron temperature was evaluated by the SXR technique and Thomson scattering diagnostic.

The first results on ICRF heating were encouraging [3]. In some regimes of the tokamak the doubling of ion temperature was observed at RF power input up to 150 kW (Fig.1). RF power was absorbed mainly by hydrogen as it was proved by fast hydrogen “tails” appearance in ion energetic spectra (Fig.2) and then both ion components got in thermal equilibrium.

The characteristic time of temperature rise at the beginning of the RF pulse and its decay after the pulse corresponded to the plasma energy lifetime for both ion components. The experimental results indicate effective energy exchange between deuterium and hydrogen

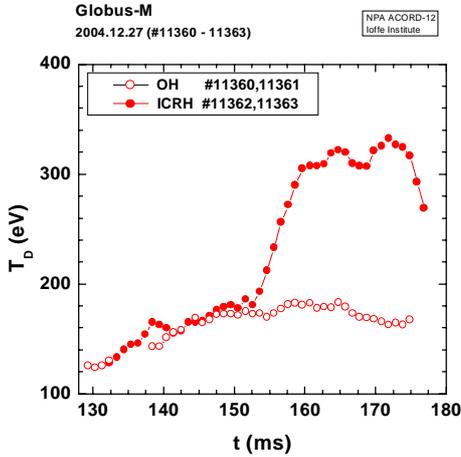


Fig.1. Evolution of ion temperature with/without RF pulse

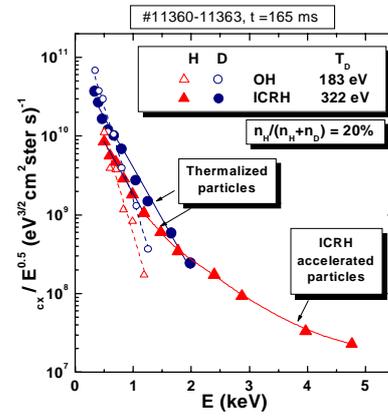


Fig.2. Ion energy spectra with/without RF pulse.

populations. Fig. 1 and 2 correspond to $I_p=185$ kA, $n_e(0)=3.10^{19}$ m⁻³, $P_{inp}=120$ kW, $f=7.5$ MHz. But effect of heating was unstable, and in a number of shots the hydrogen heating was observed at the background of a relatively low deuterium heating. This fact could be explained by peripheral RF power absorption.

To verify this suggestion, special experiments were carried out, when the toroidal magnetic field before the RF pulse was diminished step by step down to $0.8 B_{T0}$. At this procedure the layer with second cyclotron hydrogen harmonic appeared in the plasma in front of the antenna and then shifted deeper into plasma. In Fig.3 the behaviour of deuterium temperature in dependence on the toroidal magnetic field is shown. It is seen that appearance of second cyclotron harmonic and its displacement from $r=23$ cm to $r=17$ cm resulted in a decrease of the deuterium heating by 20-30%. At the same time the hydrogen “temperature” is getting higher than the deuterium one (Fig.4). This difference is more pronounced at low hydrogen concentration. Simultaneously the effective hydrogen “tail” temperature reveals stable tendency to lowering. The last fact can be accounted for by poor confinement of energetic protons at outer plasma periphery.

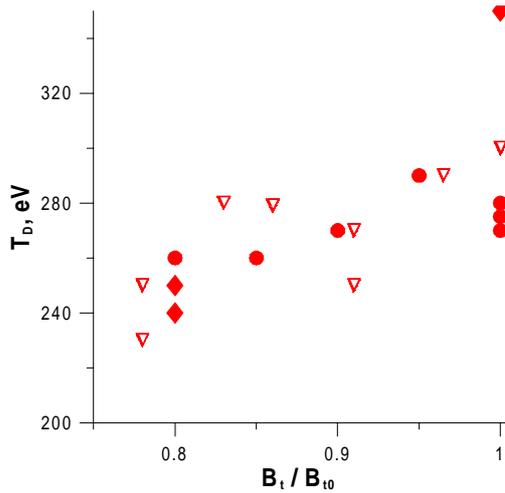


Fig.3. Ion temperature behavior in dependence on B_t
 $B_{t0}=0.4$ T, $I_p= 190$ -210 kA, $C_H=15\%$, 30%
 $f= 7.5$ MHz, $P_{inp}= 120$ kW
 In OH regime $T_D=180$ -200 eV

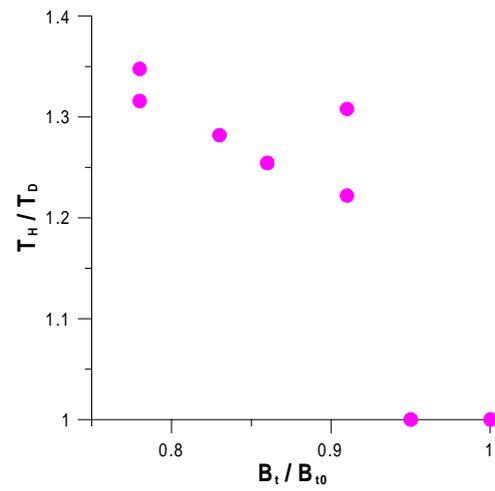


Fig.4. T_H/T_D ratio in dependence on B_t
 $B_{t0}=0.4$ T, $I_p= 190$ -210 kA, $C_H=15\%$,
 $f= 7.5$ MHz, $P_{inp}= 120$ kW
 In OH regime $T_D=180$ -200 eV

The experimental results were analyzed by the 1-D wave code [4] including all possible mechanisms of RF absorption (cyclotron, TTMP, Landau). Modeling of wave absorption was performed for frequencies 7.5, 8.5 and 9.1 MHz. In experiment the last two cases were realised at 7.5MHz heating but decreasing the magnetic field by 0.9 and 0.8 B_{t0} . It is seen that the strong power absorption by hydrogen takes place at the periphery when the 2nd hydrogen harmonic appears in the plasma (Fig.5).

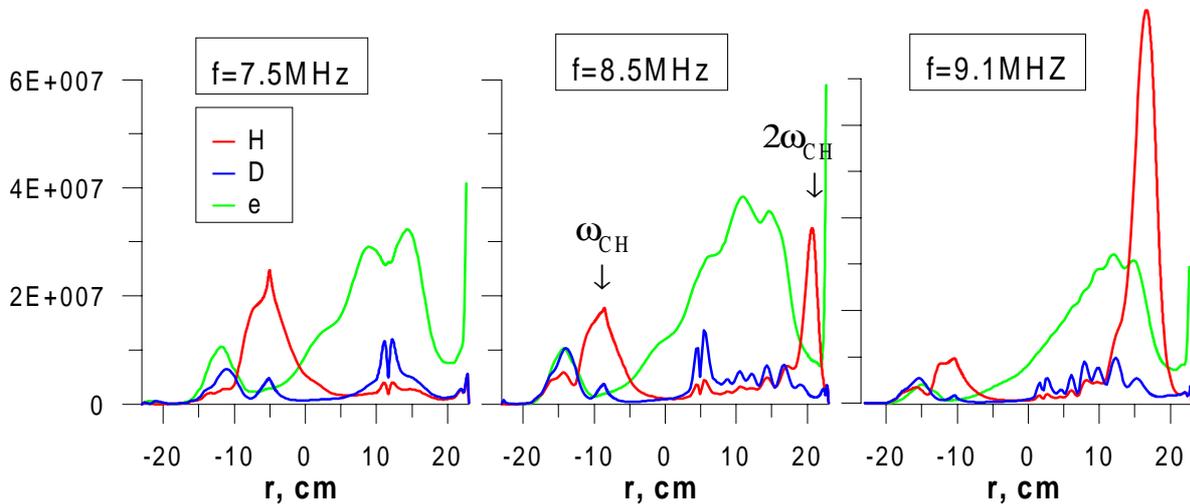


Fig.5. RF energy absorption profiles, calculated at $C_H=20\%$ for equatorial Globus-M parameters: $B_{t0} = 0.4$ T, $I_p= 200$ kA, $n_e(0)= 5 \cdot 10^{19} \text{ m}^{-3}$

In regimes when the absence of 2nd hydrogen harmonic was guaranteed the investigation of ion heating in dependence on hydrogen concentration C_H was performed. Two pulse valves were used for puffing hydrogen and deuterium independently keeping plasma density unchanged. The experiment has shown that at C_H increase from 12% up to 75% the ion heat-

ing was getting better (Fig.6). The same dependence was measured at $B_t=0.8B_{t0}$ when the 2nd H-harmonic was present in front of the antenna (Fig.7) for the same plasma parameters. Comparison of these figures confirms the fact, that the presence of the 2nd hydrogen harmonic diminished the total plasma heating (in OH regime $T_D=T_H=180-200$ eV). The enhanced difference between T_H and T_D at low C_H is connected probably with increase of the weight of peripheral hydrogen temperature in the measured one along the NPA line of sight.

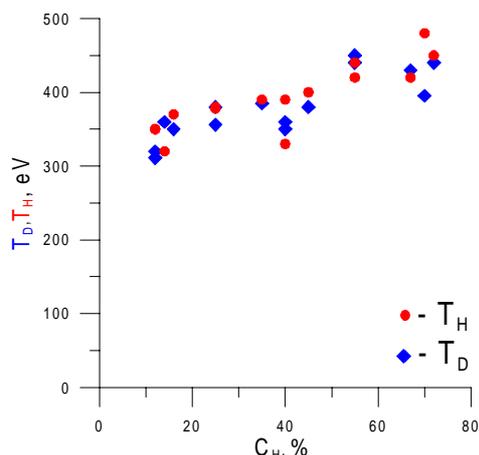


Fig.6. Ion heating in dependence on hydrogen concentration when the 2nd H-harmonic is absent.

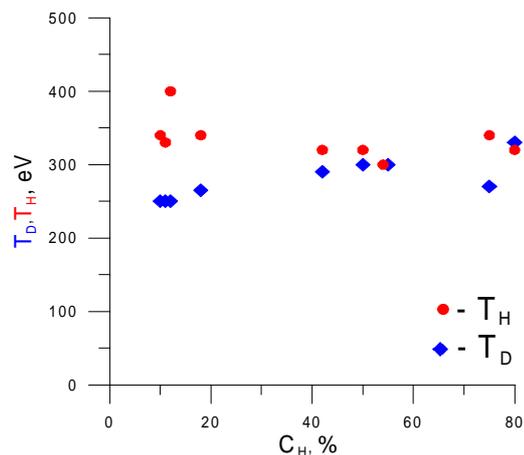


Fig.7. Ion heating in dependence on hydrogen concentration when the 2nd H-harmonic is present

At the same time the effective “H-tail” temperature decreased in average from 1.1 keV to 0.6 keV. The number of particles in fast H-tails diminished also.

The obtained results are in agreement with modeling by the same wave code of RF power absorption in broad range of relative hydrogen concentration. The simulation demonstrated that in the Globus-M conditions the fraction of RF energy absorbed by ions practically does not depend of C_H .

Reliable electron heating was not observed in these experiments.

Conclusions. 1. The location of the 2nd H-harmonic in front of the antenna decreases efficiency of ion heating in the plasma center.

2. The ion heating increases slightly with the rise of concentration of light ion component.

3. Obtained results are in a good agreement with numerical modeling by 1-D wave code.

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