HF HEATING OF PLASMA AT $\omega \approx 2\omega_{LH}$ IN TOKAMAK TM-1-MH

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Preliminary experiments on plasma heating above lower hybrid resonance at frequency $f \approx 2f_{LH}$ have been carried out in tokamak device TM-1-MH. For toroidal magnetic field 1.3T, the frequency 1.25 GHz and HF power 40 kW the increase of ion temperature of plasma up to $\Delta T_i/T_i^{OH} \approx 1$ was measured. The ion heating increases with the plasma density and a threshold character on incident HF power is observed. This HF heating is accompanied by changes in loop voltage and electron plasma density.

Recently a considerably progress in the LHR heating of tokamak plasma was achieved [1-4]. In the following results of the heating experiments at $f \approx 2f_{LH}$ in TM-1-MH device are given.

The parameters of the TM-1-MH device are as follows: R = 0.4 m, limiter a=0.075 m, maximum toroidal magnetic field B_t = 1.5 T, plasma current I_p up to 30 kA, loop voltage U_{loop} = 2-4V. Schematic arrangement of diagnostics and a position of the HF coupling element is shown in Fig. 1. A quasistationary state of the plasma discharge is reached after about 2 ms, while the total discharge length is 8 ms, see Fig. 2a. Working gas is hydrogen at initial filling pressure usually 2×10^{-2}Pa. To control the electron density, the additional pulse hydrogen gas injection by means of the piezo-electric valve is used. The effect of this additional gas injection on plasma parameters is demonstrated in Figs. 2a,b, where time dependences without the injection are given as well (dashed lines). It may be seen that while the plasma current does not change at all and the loop voltage is only slight increasing, the electron density can be increased remarkably. The magnitude of the electron density strongly influences the ion temperature (measured by 5-channel charge-exchange analyzer [6]) of the ohmically heated plasma T_i^{OH}, see Fig. 3. Maximum value of the density on the axis $N_e(0)$, given in Fig. 3, was evaluated under assumption of the parabolic density distribution, from the line averaged density measured by the 4 mm interferometer.

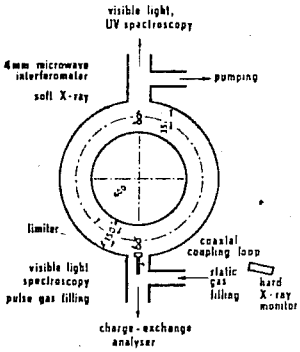

FIG. 1

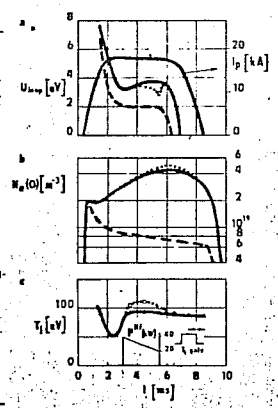

FIG. 2

Heating experiments at $f \approx 2f_{LH}$ were performed under following conditions: toroidal magnetic field B_t = 1.3 T, plasma current I_p = 17 kA, line-averaged electron density $N_e=(0.5-2.5)\times10^{19}m^{-3}$, ion temperature of the ohmically heated plasma on the axis $T_e(0)$= =50-150 eV and electron temperature on the axis $T_e(0)$= 300-500 eV (estimated from conductivity measurements, UV radiation of impurities and recently from soft X-rays as well).

As a HF oscillator the CW magnetron (f=1.25GHz, P=45kW) was used. It was operated in the pulse regime: maximum output power 50 kW, pulse length 3 ms, output power drops during this pulse to about 50% of maximum value. HF power is fed to the device through the ferrite isolator, calibrated directional couplers and impedance matcher. As a launching element a coaxial coupling loop is used. The HF power is switched on in the third ms after the beginning of the plasma pulse, that is in the moment, when the plasma current and loop voltage achieve the stationary value, see Fig. 2. All changes caused by the HF power are shown in Fig. 2 by dotted lines. For HF power of 40 kW (at the beginning of pulse) the ion temperature measured by charge-exchange increases by 25% (see Fig. 2a). The bulk of ions is not heated, but most probably a few tens percent of the total ion number only. Fig. 2a shows the effect of the HF power on the loop voltage. This voltage decreases by factor 10-20%. It corresponds to the electron temperature increase by 7-15%. The beginning of the loop voltage decrease is retarded by about 0.5-1.0 ms with regard to the beginning of the HF pulse. After HF pulse the voltage returns to the starting value quickly. The presence of HF power results in the moderate increase of the electron density by about 10% (see Fig. 2b).

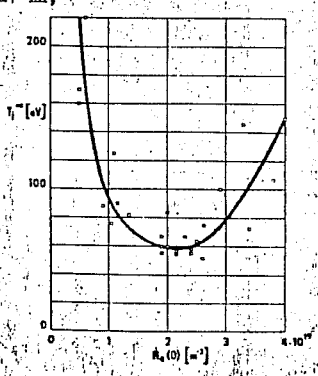

FIG. 3

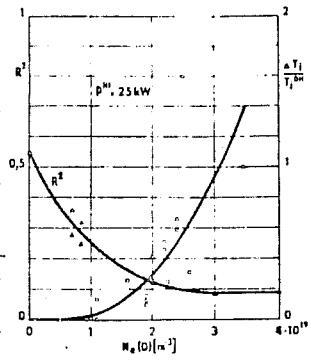

FIG. 4

The relative increase of the ion temperature $\Delta T_i/T_i^{OH}$ is shown in Fig. 4 in dependence on the plasma density for HF power 25 kW. For densities $N_e(0)$ smaller than $1\times10^{19}m^{-3}$ practically no heating is observed. Considerable heating takes place at $N_e(0)$= = $2\times10^{19}m^{-3}$ when nearly 90% of incident power is delivered to the device (see measured power reflection coefficient R^2).

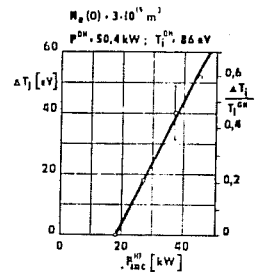

FIG. 5

Very important is also dependence of ion temperature increase on the HF power, see Fig.5. This dependence has a threshold character. Measurable HF heating is observed for powers greater than 20 kW only. The data given in Fig. 5 were obtained from spectra of charge-exchange neutrals displayed in Fig. 6. The spectra were measured in the 1 ms time gate (4-5th ms). The threshold character of HF heating is now under study.

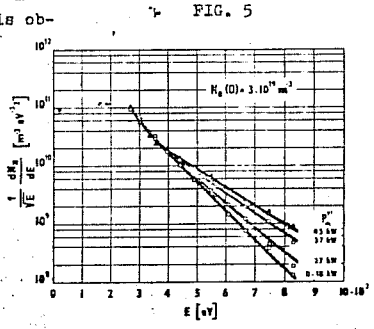

FIG. 6

It is not clear to us, if the ion heating in our experiments with additional gas injection is caused by the plasma density increase or by more efficient coupling due to change in plasma density profile. Our next experiments will be devoted to the detailed study of the influence of form and position of the coupling loops on the heating efficiency.

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