RF-HEATING OF PLASMA IN THE FREQUENCY DOMAIN OF THE ION CYCLOTRON HARMONICS

by

H.G. Hahnekamp,[+] R. Läuter, A. Stampa,[+] H. Tuczek[+], H.O. Wulf

Institut für Plasmaphysik der Kernforschugsanlage Jülich GmbH

5170 Jülich, Postfach 1913, Federal Republic of Germany

+ Universität Essen-Gesamthochschule 4300 Essen Postfach

Federal Republic of Germany

ABSTRACT: Experiments on rf-heating of plasmas in the frequency domain of the ion cyclotron harmonics are reported. The rf-power is coupled to the magneto-acoustic wave for frequencies between ω_{ci} and $5\omega_{ci}$. The measurements indicate that the damping of the pump wave is mainly due to the excitation of turbulence, whereas direct resonance at $2\omega_{ci}$ seems to be of minor importance.

Introduction. Rf-heating of plasmas for frequencies in the domain of the ion cyclotron harmonics is of interest as an additional heating method in toroidal confinement machines. For this freqency regime the external rf-power is primarily coupled to the fast hydromagnetic wave, which must be damped by some collisionfree process. Previous investigations have shown that the dissipation may be achieved by the excitation of the modified two stream instability /1/. The necessary electrical field, however, is rather high for the application in fusion machines. We therefore looked for heating mechanisms working with smaller rf-amplitudes. Several such processes have been considered theoretically /2/, /3/. In order to facilitate the comparison of the theoretical predictions with our experimental results we used a new type of plasma source, which allows the production of a low density fully ionized collisionfree plasma with low impurity level. In this experiment the investigations were performed in linear geometry. The effects of toroidal geometry are studied in an experiment of tokamak-like configuration.

Linear Experiment Figure 1 shows a schematic diagram of the linear device. A fast electromagnetic valve admits a gas pulse into the evacuated discharge tube. A slow theta pinch produces a plasma with a density of the order 10^{14} cm^{-3}. This plasma expands with a streaming velocity of about 10^{6} cm/s along the diverging magnetic field lines into the region of a homogeneous quasi-static guiding field of 260 or 330 Gauss, respectively, whereby the density is reduced by two orders of magnitude. By this technique one gets a fully ionized mangetized plasma with a low density and a low impurity level, because the neutrals and the heavier ions should have a smaller velocity than the expanding plasma.

The pump wave is excited in the plasma by a 1.8 m long Stix-coil, which is part of a tank circuit of a pulsed 1 MHz-transmitter with a maximum power output of 500 kW.

The power consumption of the plasma was evaluated from measurements of the voltage at the tank circuit and the current flowing into the tank circuit. Figure 2 shows the power consumption of the plasma as a function of the power delivered by the transmitter. The degree of modulation of the static field by the magnetic field of the pump wave ranged between 1.5 and 6 %. In the frequency range between 2 and $5\omega_{ci}$ an effective energy transfer to the plasma is observed. Measurements were made at 2, 2 1/2, 4 and $5\omega_{ci}$. For all these frequencies the curves coincide within the accuracy of the measurement. Therefore, direct resonance effects of the pump wave with the ion cyclotron motion at $2\omega_{ci}$ /2/ and the decay into ion Bernstein waves at $n\omega_{ci}$ $(n > 2)$ /3/ must be of minor importance. The measured energy transfer cannot be explained with the classical (Spitzer) collision frequency. From this, we conclude that the energy transfer from the rf-circuit is established by some other turbulent effects.

There is a pronounced kink in the curve at a modulation degree of 4.6 % which separates two domains, one domain of low amplitude and another one of higher amplitude, where the relative power consumption of the plasma is increased. It may be assumed that the enhanced energy transfer in the high amplitude domain is caused by the onset of another microinstability with a higher threshold.

The electron temperature was measured with an electrostatic double probe, the ion temperature with a retarding field particle analyzer. In order to avoid disturbances of the probe signal by the high frequency field, some of the measurements had to be done after fast switch-off of the high frequency pulse. The measurements show an increase of both T_i and T_e. Maximum measured temperatures are T_i = 70 eV - 100 eV for initial temperatures $T_i \approx 2$ eV, the electron temperature always being lower than the ion temperature.

This ion temperature increase is an accordance with an estimation from the total amount of rf-power delivered to the plasma (67 kW). Figure 3 shows the electron density as a function of time measured by an 8 mm microwave interferometer. Without rf-field the density is nearly constant during 200 μsec. On the other hand 20 μsec after the rf-field has reached its full amplitude, there is a rapid decrease in density which may be caused by the enhanced axial plasma losses due to the temperature increase.

<u>Toroidal Experiment.</u> This experiment (Figure 4) is a compact axisymmetric torus (R = 25 cm) with large aspect ratio ($\frac{r}{R}$ = 0.4). The main field coil is helically wound and produces the toroidal field as well as the plasma current. The equilibrium position is regulated by an additional vertical B_z-field and a stabilizing copper shell. The energy for the initial plasma is supplied by a 60 kJoule condenser bank discharge which is crowbarred at current maximum. The configuration is tokamak-like with a plasma current below the Kurskal limit (toroidal field 6 kGauss, plasma current 24 kA). Four single turn rf-coils with current in opposite directions excite the pump wave at a transmitter power level of 1 MW.

First measurements were done with H_2 as filling gas and reduced energy of the condenser bank (E = 6 kJoule, B_φ = 2 kGauss, I_φ = 8 kA). The pump frequency was 1.2 MHz. The distribution of the pump wave amplitude over the plasma cross section shows that it is possible for certain plasma parameters to excite radial eigenmodes of the plasma torus with respect to the com-

pressional MHD wave. At resonance an enhancement of the toroidal component of the rf-magnetic field from the plasma boundary to the axis by a factor 6 - 8 was measured.
At the same time an enlarged energy transfer from the external circuit to the plasma during geometric resonances was observed. Thus, the macroscopic phenomena concerning coupling and energy transfer to the plasma show the same characteristic features as in the linear experiment. In the present stage of our experiment the initial plasma is not collisionfree so that no direct conclusion to fusion plasmas may be derived. But with additional heating by the observed geometric resonance and enlargement of energy confinement time by the use of the 60 kJoule condenser bank, it should be possible to reach the conditions of a collisionfree plasma, in order to investigate the influence of the toroidal geometry to the dissipation mechanism observed in the linear experiment.

References

/1/ K.H. Finken, A. Stampa, H. Tuczek, Z. Naturforschung 30 a 195 (1975)

/2/ J. Adam, A. Samain, EUR-CEA-FC-579, 29 (1971)

/3/ K.D. Harms, G. Hasselberg, A. Rogister, Nuclear Fusion 14, 251 (1974)

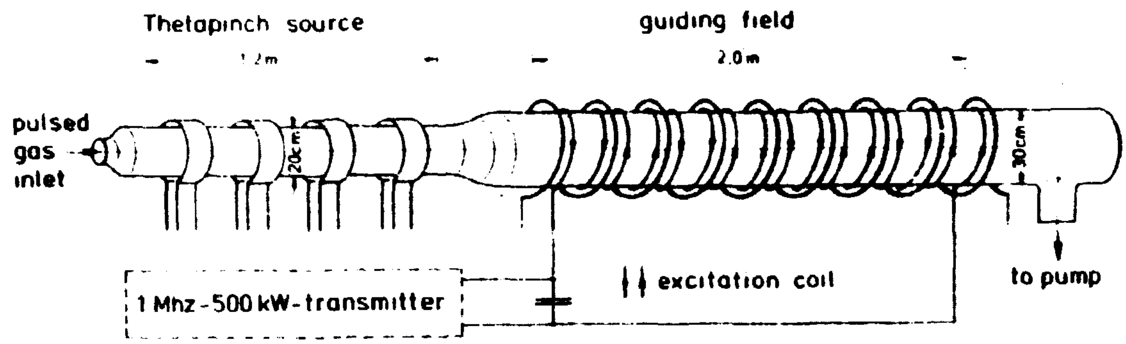

Figure 1 Experimental arrangement of the linear device

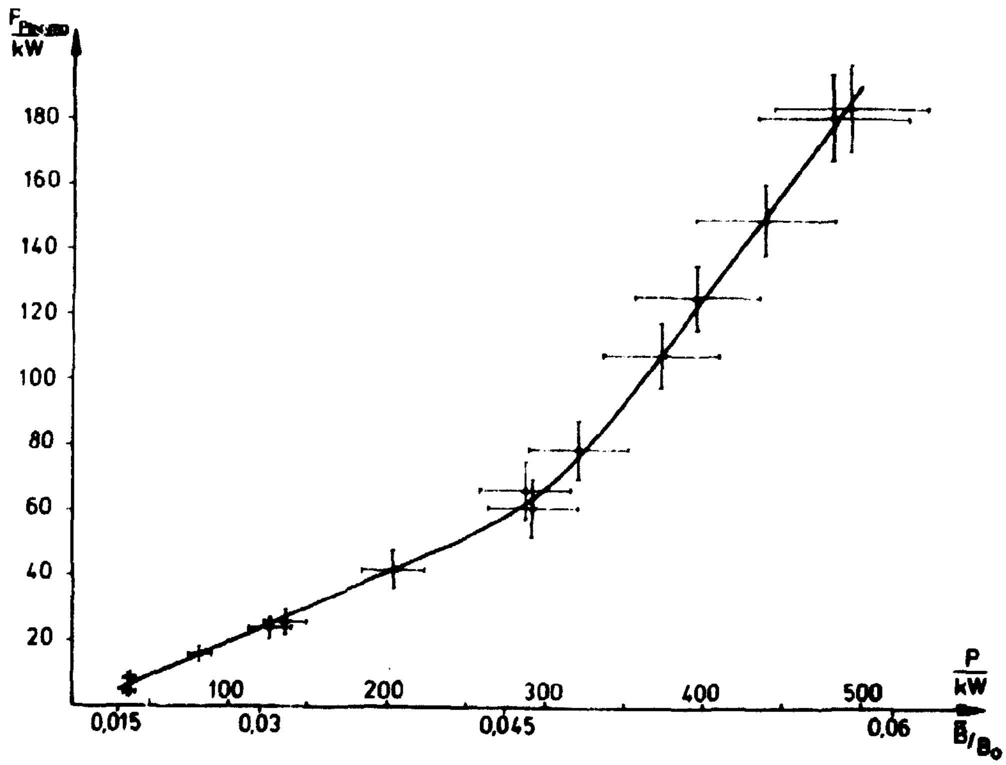

Figure 2 Energy consumption of the plasma as a function of rf-power delivered by the transmitter

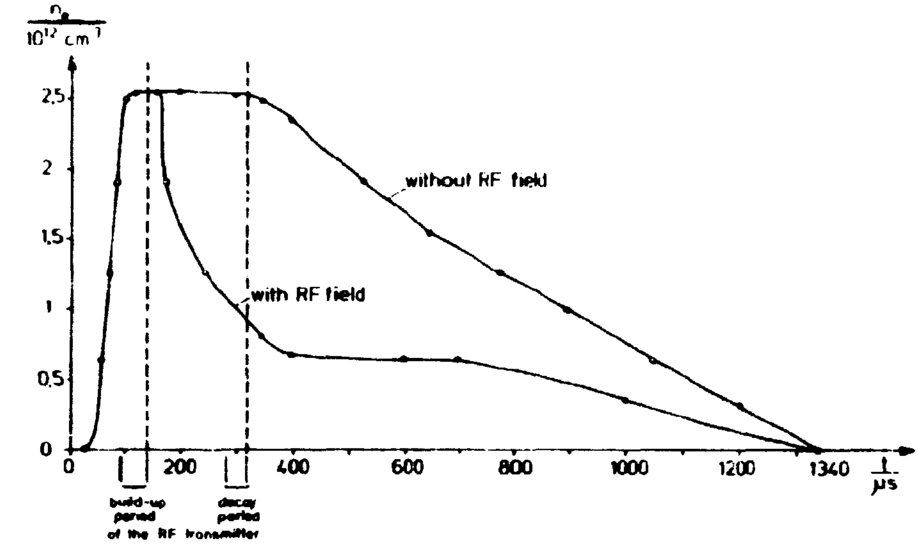

Figure 3 Electron density as a function of time measured by an 8 mm microwave interferometer

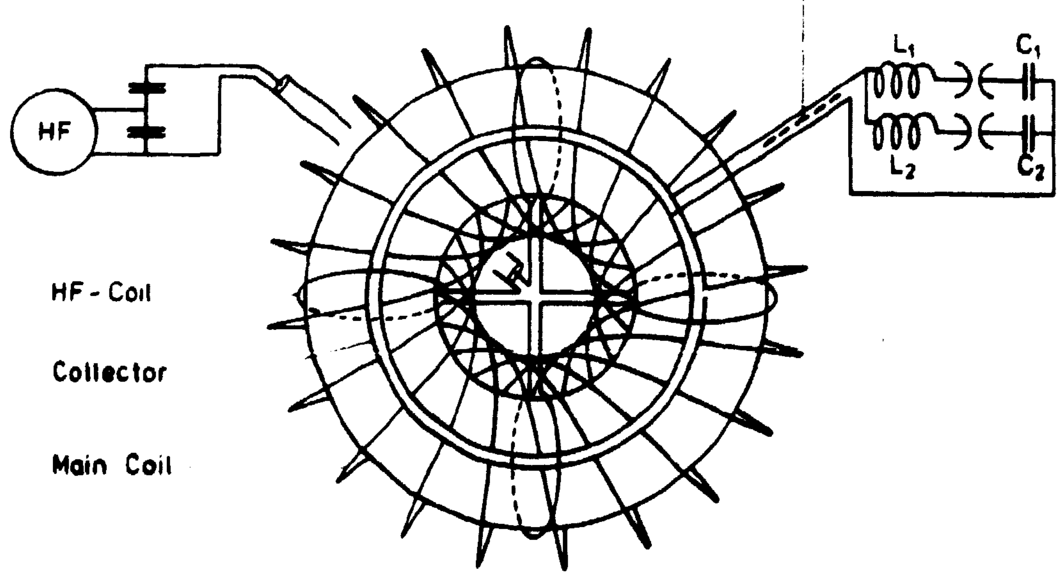

Figure 4 Experimental arrangement of the toroidal device