LOWER HYBRID EXPERIMENTS AT 2.45 GHz IN ASDEX

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ABSTRACT

The new lower hybrid system of ASDEX has started operation. A power level of 1 MW/0.5 sec was meanwhile achieved. Current drive and heating have been studied until now up to a density of $n_e \approx 3\cdot10^{13}\text{cm}^{-3}$. Central heating of electrons and ions is seen.

A new lower hybrid system with $f = 2.45$ GHz, $P = 3$ MW and $T = 1$ s has been constructed for use on ASDEX. The main aims are to study profile control with simulataneous application of other heating methods. The higher frequency of 2.45 GHz, as compared to the previously used 1.3 GHz, allows operation in the typical density regime for neutral injection and ion cyclotron heating in ASDEX. For this purpose a high flexibility with respect to the launched wave spectrum was required. The system has started operation at the end of 1988.

The transmitter consists of two groups of 3 klystrons which are fed by a common dc-power supply and which are protected by a common ignitron crowbar system. They can be operated independently. All 6 klystrons are fed by a common masteroscillator. Their outputs are amplitude- and phase controlled (20 dB; 360°) by means of feedback systems acting on the respective RF-inputs. The amplitude control is also used for modulation.

Standard WR 430 transmission lines connect the 6 klystrons to a power splitter unit based upon 3 dB E-plane hybrids and providing 6 x 8 outputs to feed a 2 x 24 waveguide grill. The phase of each output can be arbitrarily set through 360° by step motors allowing the generation of current drive spectra, opposite current drive spectra and symmetric wave spectra at variable $N_\parallel$ ($1 < \bar{N}_\parallel < 4.4$, $\Delta N_\parallel = 0.4$). Due to an excellent isolation of the 3 dB-hybrids the forward waves are insensitive to arbitrary reflections.

The grill consists of 2 arrays of 24 waveguides each. Their inner dimensions are 10 x 109 mm, the wall thickness is 4 mm. Two front window blocks of PLT-design are located ca. 25 cm from the plasma surface. The front ends of the grill are made of stainless steel and their waveguide inner surfaces are coated with a rough gold layer to prevent multipactors. The upper and lower waveguide arrays are connected to the two groups of klystrons and can be operated independently with different powers and different spectra. In all 48 waveguides the incident and reflected powers are measured. The phases of the incident waves are monitored twice during a 1 sec pulse with a time multiplexing device.

The system was constructed in cooperation between ENEA-Frascati (grill, narrow waveguide structures, 3 klystrons), PPPL-Princeton (waveguide windows, 3 klystrons) and IPP-Garching. It was put into operation in December 1988 and after a total of 80 shots at different phase settings and plasma conditions we achieved a power level of 1 MW/0.5 s into a $3 \cdot 10^{13}$ cm^{-3} plasma.

The coupling is usually good with a global RF reflection coefficient <R> between 10 and 25 %, depending on grill-position and plasma position. In the individual waveguides the reflection coefficients are, however, quite different. An example is shown in Fig. 1, where we compare the distribution of the reflection coefficients in one grill for the case of normal and opposite current drive. In a few shots we varied the relative phase between the upper and the lower grill and found very little influence on their reflection distributions.

The results of the first current drive experiments are summarized in Fig. 2. Here we plot the rate of change of the primary current in the OH-transformer during the lower hybrid pulse, normalized to its value in the preceeding OH-phase. We recognize the nonlinear decrease of this quantity with the RF-power and its variation in the limited range of densities studied up to now. For comparison we also show the points which have been obtained with the old 1.3 GHz system in the same density range /1,2/. The improvement with frequency is obvious.

In the parameter range studied until now, the RF power is directly absorbed by suprathermal electrons. Contrary to the previous experiments at 1.3 GHz /1,3/ no fast ion tails were observed up to the maximum working density $\bar{n}_e \approx 4 \times 10^{13}$ cm^{-3}. Similar observations were made in the FT-tokamak /4,5/. The generation of suprathermal electrons leads to a strong increase of hard X-ray radiation and nonthermal ECE spectra as measured with a Michelson interferometer. Thermalization of the fast electrons leads to an increase of the electron temperature over the whole plasma cross-section as from the YAG-Thomson scattering measurements. The radial profile of $T_e(r)$ is slightly peaking during Lower Hybrid current drive. The peakedness $T_{eo}/\langle T_e \rangle$ increases with increasing LH power. At $\bar{n}_e = 2.1 \times 10^{13}$ cm^{-3} the central electron temperature nearly doubles from $T_{eo} \approx 1.7$ keV to $T_{eo} \approx 3.2$ keV with $P_{LH,t} = 750$ kW applied. The radial profiles of $T_e(r)$ during the OH and LH phases are shown in Fig. 3. The central temperature T_{eo} increases linearly with LH power as seen from Fig. 4. The increase in ion temperature, measured by perpendicular CX-diagnostics, is smaller at low density where the coupling between electrons and ions is weak. At $\bar{n}_e = 2.1 \times 10^{13}$ cm^{-3} with $\Delta T_{eo} = 1.4$ keV an increment of only $\Delta T_{io} = 0.2$ keV is obtained with $P_{LH,t} = 750$ kW. . The increase in thermal energy content, as determined from the diamagnetic signal, is only slightly larger than the increase in the electron energy content as measured with Thomson scattering. The increase in total energy content as derived from the equilibrium beta is typically a factor of 1.3 larger than the increase in thermal energy content. The difference has to be attributed to the higher parallel component of the suprathermal electrons. At higher density, the anisotropy is reduced and also the coupling between electrons and ions is improved. At $\bar{n}_e = 2.75 \times 10^{13}$ cm^{-3}, $\Delta T_{eo} \approx 1$ keV and $\Delta T_{io} \approx 0.3$ keV are obtained with $P_{LH,t} = 590$ kW. The absorption coefficient $\alpha = P_{LH,abs}/P_{LH,t}$ can be derived from the rate of change of the energy content immediately after switch-off of the LH power. For the actual experiments ($\bar{N}_{\parallel} = 2.25$, $\Delta \varphi = \pi/2$) we obtain $\alpha \approx 0.5$.

The sawteeth period rises with increasing LH power as was already found at 1.3 GHz /6/. With dominant LH-current drive, sawteeth are suppressed completely. For the series at $\bar{n}_e = 2.1 \times 10^{13}$ cm^{-3} shown in Fig. 4, sawteeth are stabilized for $P_{LH} \gtrsim 750$ kW. The RF-current drive in this case results in a drop of OH power input by about 2/3. After stabilization of sawteeth, central electron temprature and beta values start to increase continuously with a moderate slope.

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Fig. 1:
Distribution of refleciton coefficients in the upper grill for normal and opposite current drive.

Fig. 2:
Rate of change of the primary current as a function of LH-power

Fig. 3:
The radial electron temperature profiles during OH and LH-phase.
$\bar{n}_e = 2.1 \times 10^{13}$ cm^{-3}, $P_{LH} = 750$ kW, $\bar{N}_{\parallel} = 2.25$, $\Delta \varphi = \pi/2$.

Fig. 4:
Scaling of the central electron temperature T_{eo} and of the sawtooth period with LH-power.

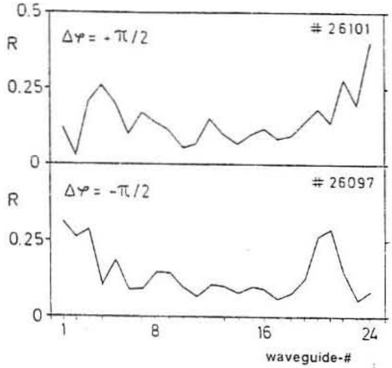

Figure 1

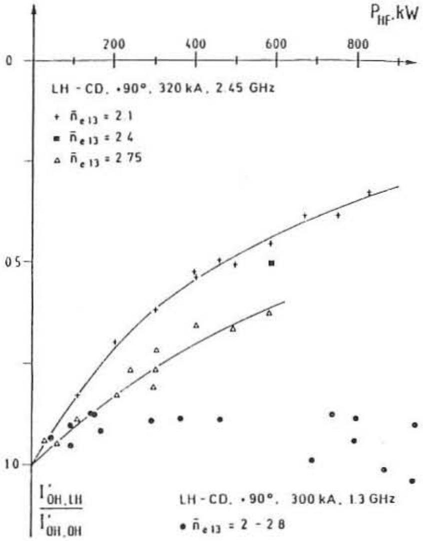

Figure 2

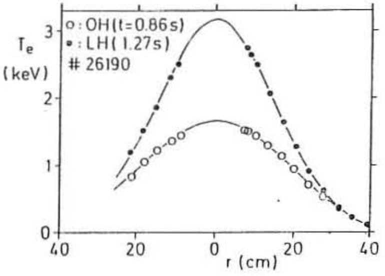

Figure 3

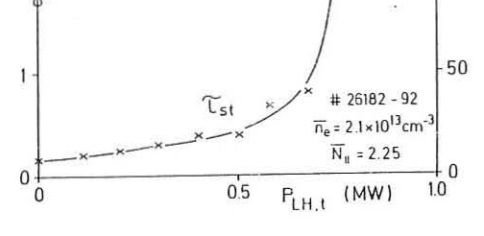

Figure 4