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# Coupling LHW Power to Plasma by Gas Puffing in HT-7

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Abstract Long distance coupling experiments in HT-7 were carried out with the method that the gas is puffed just around the antenna. Without gas puffing, only 115kW LHW are injected when the distance is up to about 8cm. By means of the $CD_4$ puffing, the maximum of the 230kW LHW is stably coupled to the plasma by means of this gas puffing. The variation of the lined averaged density in the different channel gives a possible evidence of the ionization mechanism of neutral gas. The effect of the gas flow rate on the wave–plasma coupling shows that an optimized gas flow rate is necessary for good coupling.

1. Introduction Lower hybrid current drive (LHCD) has proven to be one of the most efficient methods of non-inductive current drive and off-axis current profile control in tokamak experiments. Theory studies [1,2] indicate that the plasma density at the grill mouth ($n_{e,grill}$) and its gradient are two key factors determining wave-plasma coupling. In order to avoid heavy heat load and to satisfy different plasma configurations, it is necessary to increase the distance between the antenna and plasma. As a result, the coupling of LHW and plasma will be deteriorated due to the decrease of $n_{e,grill}$. Also, in the H-mode plasma, the edge density will decrease rapidly enough that $n_{e,grill}$ does not satisfy the wave-plasma coupling condition, resulting in a large reflection. Consequently, LHW power cannot be effectively coupled to the plasma. These are inevitable problems in the coming EAST experiment and ITER operation.

To solve the long distance coupling between LHW and plasma, a kind of neutral gas (e.g., $CD_4$, $D_2$) is utilized to increase $n_{e,grill}$. Such long distance coupling experiments have been done and analyzed in devices JT-60U, Tore-supra, and JET, on all of which the gas is injected from one side of the LHW antenna [4-7]. In order to pre-perform something for EAST and ITER and to further understand the related physics on coupling improvement by gas injection, it is necessary to try the relevant experiments in HT-7 tokamak, on which the gas is injected around the LHW multi-junction antenna so that the magnetic connection is guaranteed

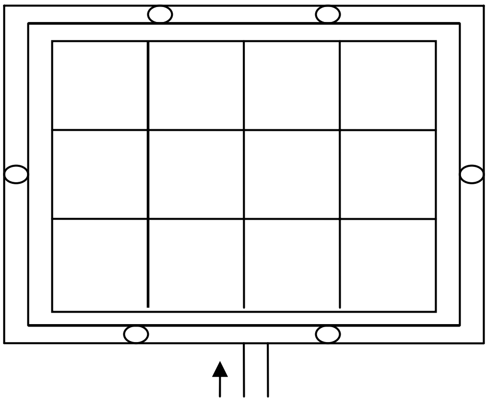

Fig. 1 Setup sketch of the gas puffing structure

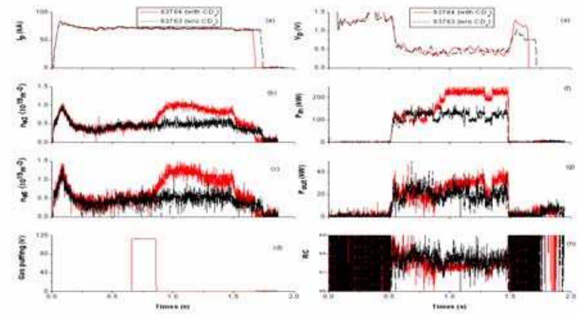

Fig.2 Waveforms of with and w/o $CD_4$ puffing with d = 8cm

whenever at any plasma current and magnetic field.

2. Setup and experiments The gas is puffed through an electric magnetic valve of PV-10, which will be open when applying a voltage above the threshold on it. The setup sketch is shown in Fig.1, where 12 rectangles are LHW grills, which is surrounded by the gas pipe, along which there are 6 holes used for gas injection.

The experiments were performed with the following parameters: plasma current of Ip=70kA, magnetic filed on the magnetic axis of $B_t$=1.8T, central line averaged density of $n_e=0.5\text{x}10^{19}\text{m}^{-3}$, and peak value of parallel refractive index of $N_{//}^{peak}$ = 2.55 with a LHW frequency of 2.45GHz. In the experiments, the working gas for plasma is deuterium and the puffing gas is selected as $CD_4$. Since the location of LHW antenna can not be changed in the experiment, the distance between the plasma and the grill (d) is changed by moving the plasma horizontal displacement so as to change the minor plasma radius with the help of the poloidal limiter in the high field side. The maximum of d is limited to about 8cm due to the plasma disruption. The results with such d = 8cm are shown in Fig.2, where plasma current ($I_p$), line averaged density $n_{e3}$ and $n_{e5}$, gas puffing signal, loop voltage ($V_p$), input power ($P_{in}$), reflected power($P_{out}$), reflection coefficient (RC) are outlined from (a) to (h). It is seen that without gas puffing, the plasma densities almost keep constant and only 115kW LHW are injected. By means of the gas puffing $CD_4$ with the pressure of P=1.3 Pa, the plasma densities increase and the maximum of the 230kW LHW (the setting value) is coupled to the plasma, indicating the plasma density is effectively increased to above the critical value by the $CD_4$ puffing. We also performed the experiments to see the effect of gas puffing on wave-plasma

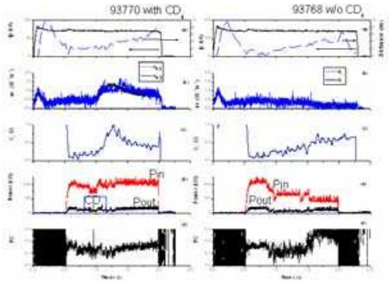


Fig. 3 Waveforms of with and w/o $CD_4$ puffing with varied distance in one discharge

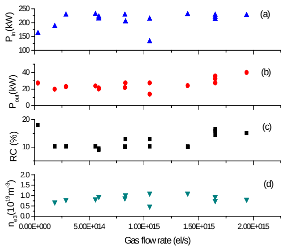


Fig. 4 Effect of gas flow rate on wave-plasma coupling

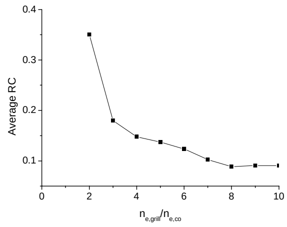


Fig. 5 Calculated reflection coefficient vs grill mouth density

coupling by moving the horizontal displacement in one discharge. The results are shown in Fig. 3. It is shown that in one discharge, with d up to 8cm, the LHW can be stably coupled to the plasma by means of this gas puffing, whereas for the case without the gas puffing, the input power decreases with the increasing distance. These suggest that $CD_4$ is effectively to increase the grill mouth density, hence improving wave-plasma coupling.

In addition, we analyzed the effect of gas flow rate on wave-plasma coupling with $B_t$ = 1.9T. The result (see Fig. 4) shows that when the gas flow rate is larger than 2.5 x $10^{14}$ el/s, the input power access to a larger and more stable value. Low reflection coefficients are obtained in the moderate gas flow rate, where a higher plasma density, which benefits the wave-plasma coupling, is achieved. Though the effect of gas flow rate on plasma density is not understood completely, the obtained influence of density on RC is also consistent with and interpreted by the study that for a good coupling an optimal density required at the antenna aperture is given by $n_{e,grill}^{opt} \geq N_{//}^2 n_{e,co}$ [8]. Simulated relationship [1] between RC and grill mouth density (see Fig .5) with $N_{//}^{peak}$ = 2.55 in HT-7 also indicates that the grill mouth density above the cut off density is necessary for good coupling, or else RC increases rapidly with decreasing density near the cut-off density.

3. Analysis and discussion The improvement of coupling indicates that the density at the grill mouth increased above the cut off value. The density improvement can be inferred from the increase of line averaged density in Fig.2 and Fig. 3, where signals of $ne_3$ and $ne_5$ represent the line averaged density at r=0 cm and r= -14cm (here "-" means high field side), respectively. There are two mechanisms of ionizing the neutral gas: electron temperature and

RF electric field. It is seen in Fig.2, $ne_3$ is a little smaller than $ne_5$, possibly due to the neutral gas is mainly ionized by the LHW electric field in the edge region. Since the temperature is lower than that in the core region, it is natural the density increase in the edge mainly results from the RF electric field, whereas in the core region, the temperature plays a larger role in increasing the density. This can be identified by the different variation rate of $ne_3$ and $ne_5$ shown in Fig.3, where after gas injection, $ne_5$ increases faster than $ne_3$. Of course, with the movement of displacement to the high field side, the laser-passing-actual line length of $ne_3$ will decrease and the one of $ne_5$ will increase. This is another possible candidate for the difference in $ne_3$ and $ne_5$. The central density increase is possibly due to the fact the radial dimension in HT-7 is much small and the radial diffusion of $CD_4$ is very fast.

4. Conclusions Long distance coupling experiments in HT-7 were carried out with the method that the gas is puffed just around the antenna, showing that $CD_4$ puffing is effective to improve the wave-plasma coupling. By means of the gas puffing $CD_4$, the maximum of the 230kW LHW is stably coupled to the plasma. The variation of the lined averaged density in the different channel offers a possible mechanism of the ionization of neutral gas. The effect of the gas flow rate on the wave–plasma coupling shows that an optimized gas flow rate is necessary for good coupling. The further experiment and analysis will be done next.

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