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ABSTRACT

Good coupling of LH power at plasma-launcher distance of 15 cm has been obtained at JET. Near-gas injection is used to increase the density in front of the grill. The role of LH power in the density increase at constant gas level is demonstrated. For the first time at JET the temperature of the hot spots caused by parasitic absorption of LH power has been measured.

INTRODUCTION

Lower hybrid current drive is the most efficient way of driving off-axis current in plasma. A key question for the use of LH on future devices is the coupling of the waves over a large plasma-antenna distance and during ELMs. This should be demonstrated on present machines. Because of its size, JET enables coupling studies over ITER-relevant plasma-launcher distances of 15 cm, in H-mode plasma with ITER-like triangularity (δ). It also allows to test different gas injection locations, including a specially designed gas pipe situated near the launcher. Previous experiments showed that by puffing gas from this gas pipe, the far scrape-off layer density ($n_{e,SOL}$) can be increased locally i.e. in the flux tube magnetically connected to the LH launcher, to values sufficient for good LH coupling, without affecting the density at the separatrix [1,2].

COUPLING OF LH POWER, AND HOT SPOTS

In recent campaigns at JET, dedicated experiments were performed to investigate the LH coupling over a long SOL in ITER-relevant plasma conditions. The demonstration needs to be done in H-mode, preferably with type-I ELMs. In these conditions LH coupling is hard because the electron density in front of the launcher, $n_{e,grill}$, is low due to the short decay length of $n_{e,SOL}$. Moreover, the electron density varies because of the ELMs. In order to increase $n_{e,grill}$, gas puffing from a dedicated gas pipe is used. This pipe (GIM6) is located on the outer wall, ~1.2m from the launcher so that it is always magnetically connected to the grill. Only D_2 was used in the experiments presented here, since previous experiments showed that D_2 is more favorable than CD_4 [2].

The experiments were performed in a scenario used for Internal Transport Barrier development, with magnetic field B_T=3.0 to 3.1T. To obtain H-mode, NBI heating between 14 and 18 MW was used. In some pulses up to 3MW of ICRH power was applied. The LH power (P_{LH}) varied from 0 to 3.2MW and the grill position (LPOS) was 2cm behind the poloidal limiters. The distance between the last closed flux surface and the limiter varied between 5 and 13cm. The amount of D_2 from GIM6 varied from 0 to 6×10^{21}e/s.

The coupling studies were performed in plasmas with high δ (δ_{low} = 0.48, near that for ITER). To get an ITER relevant distance of 15cm between the grill and the last close flux surface (LCFS) the plasma was pushed 13cm away from the poloidal limiters.

Good coupling of LH power (2.4MW) was obtained with strong total gas injection of 20×10^{21}el/s even without any gas from the near-launcher pipe, as can be seen in Figure 1, left frames. In this case, the baseline D_a signal is high, suggesting that a large amount of neutrals is present in the SOL.

The reflection coefficient averaged over 1s (RC_{ave}) was ~5% in this case although it is up to 10% on the lowest row of the grill. This is believed to be because the lowest row is furthest away from the plasma due to the plasma shape not matching that of the launcher. When 4×10^{21}el/s D_2 from GIM6 was introduced, the coupling of the bottom row recovered and RC_{ave} on that row was reduced to ~1%. The RC_{ave} for the whole grill was about 4% in this case. In another pulse the coupling was lost when the total gas was cut to zero (Figure 1, right frames). As a result, the baseline D_a was lower, indicating that a smaller amount of neutrals was present in the SOL. As seen from RC, in the phase without gas injection, the LH coupling was very bad. Good coupling was recovered (RC_{ave}=4%), when gas (4×10^{21} el/s) from GIM6 was added. The maximum power that was achieved at the large plasma-launcher distance was 3.2MW.

Reciprocating Langmuir Probes (RCP) were used to measure the far SOL plasma. The probe is located at the top of the machine but was magnetically connected to the launcher and the near-launcher gas pipe. During gas puffing the measurements between ELMs clearly show an increase in the saturation current, which is proportional to n_e. When gas is puffed from the near-grill pipe, a plateau in the saturation current profile is seen at 8 to 13cm from the separatrix, (Figure 2, left frame). However, when gas is injected from the divertor region, the saturation current near the separatrix increases. This is not desirable since an increase of n_e at the separatrix could affect the main plasma performance.

The RCP measurements also show an increase in the saturation current when the LH power was increased from 1MW to 2MW between reciprocations; (Figure 2, right frame). The gas level from the near launcher pipe was kept constant at 1.3×10^{21} el/s. RC_{ave} on the bottom row of the grill during the two reciprocations was 20% and 10%, respectively. This shows that the LH power clearly affects the density increase in front of the launcher.

Experiments in L-mode plasma showed that at P_{LH}=1MW the coupling was lost if the power was evenly distributed over the grill area. With 2MW good coupling was recovered. The reflection coefficients at the lower power level were about 40 % while they were 4% at the higher power level. However, when the 1MW was produced by only the middle part of the grill the reflection remained low at 6%. This strongly suggests that it is the LH power density (and hence probably the electric field at the gill mouth) that is the key parameter in the density increase rather than the absolute power.

In several LH experiments, localized hot spots have been observed on components magnetically connected to the grill region [3]. The most probable reason is the fast electron generation by parasitic absorption of LH power in front of the grill mouth. On JET, bright spots caused by LH power have been reported previously [4]. For the first time at JET these spots can be studied quantitatively with the new wide view infrared camera [5].

The hot spots have been studied in both high and low δ H-mode plasmas, and L-mode plasmas. The best possibility to study the spots is in L-mode, where the plasma is quiet and ELMs do not disturb the signal. Increasing wall temperature on localized spots on the limiters is observed, which is related to the LH power. The temperature may increase over 100 degrees in a few seconds and starts to decrease when P_{LH} is turned off. Moreover, the heating rate seems to depend on P_{LH}. Figure 3 (left frame) shows a typical case observed during this study. The temperature on the wall starts to decrease already when P_{LH} is decreased below 2 MW. However, when the 1 MW is produced by the middle row only, an increase in the temperature of the spot can be seen. This suggests that it is the LH power density that plays the major role here also. The temperature increases with decreasing plasma-wall distance as is seen in Figure 3 (right frame).

SUMMARY

Very good coupling at an ITER-relevant plasma-launcher distance in H-mode plasma with high δ has been demonstrated at JET. Up to 3.2 MW of LH power was coupled with a reflection coefficient of about 5% over a distance of 15cm. RCP measurements confirm the density increase in front of the grill during near-gas injection. Strong evidence has also been found of the role of LH power in the $n_{e.SOL}$ increase at constant gas level. The key parameter seems to be the LH power density rather than the total power.

For the first time on JET, it is now possible to get quantitative data on the hot spots. The studies reveal that the wall temperature measured by the new wide view infra-red camera increases by over 100 degrees during the LH phase. The temperature depends on the LH power as well as the gas injection level and the plasma-wall distance.

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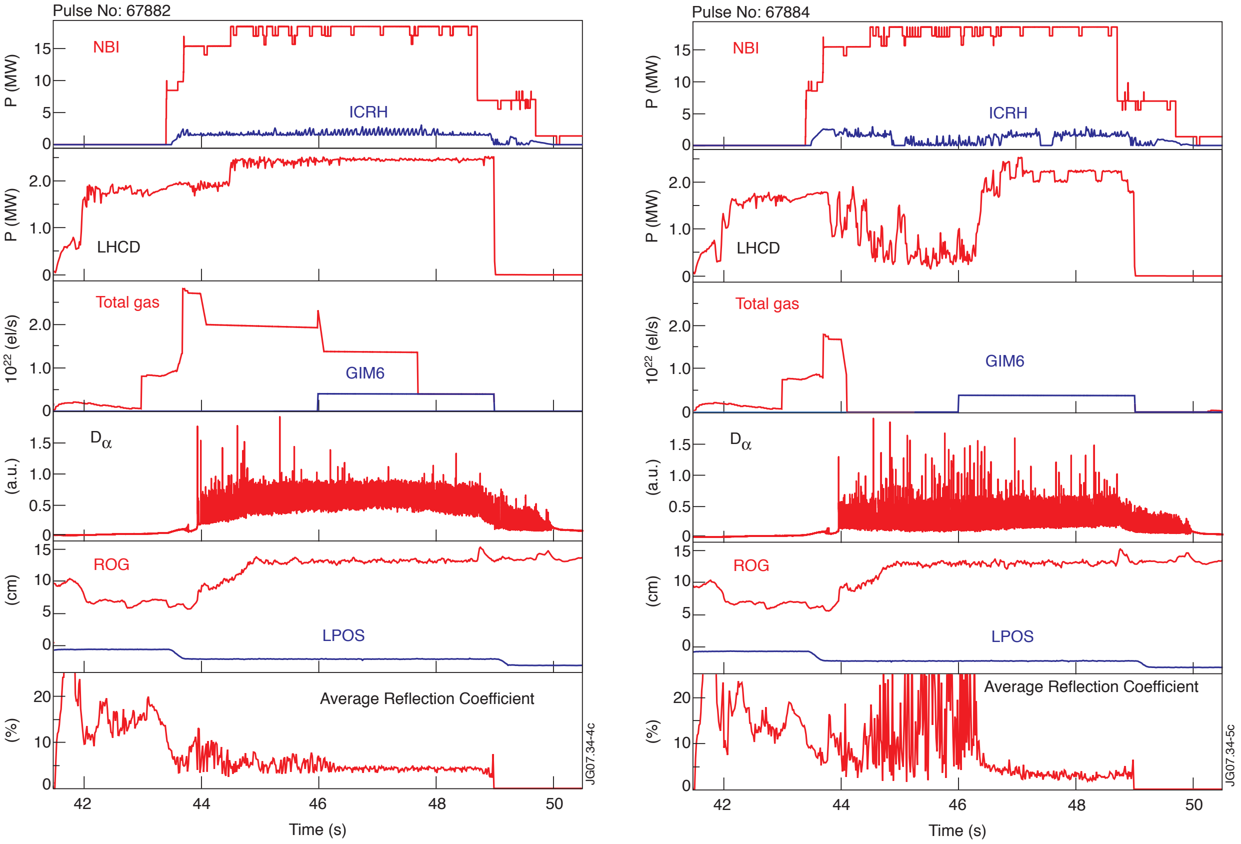

Figure 1: Long distance coupling with various gas injection levels. The near grill gas injection is denoted by GIM6 which is the only gas injection starting at 46s in pulse 67884.

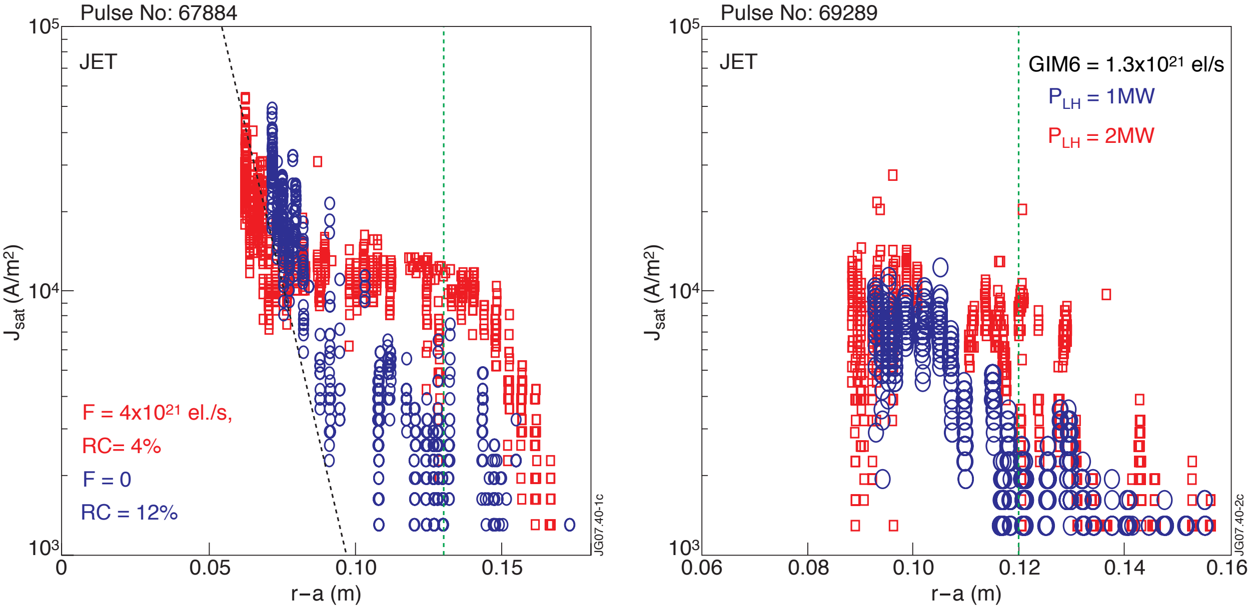

Figure 2: Saturation current measured by the RCP, as a function of the distance from the separatrix. A clear increase is seen due to the gas injection from the near-grill pipe GIM6 (left) and LH power (right).

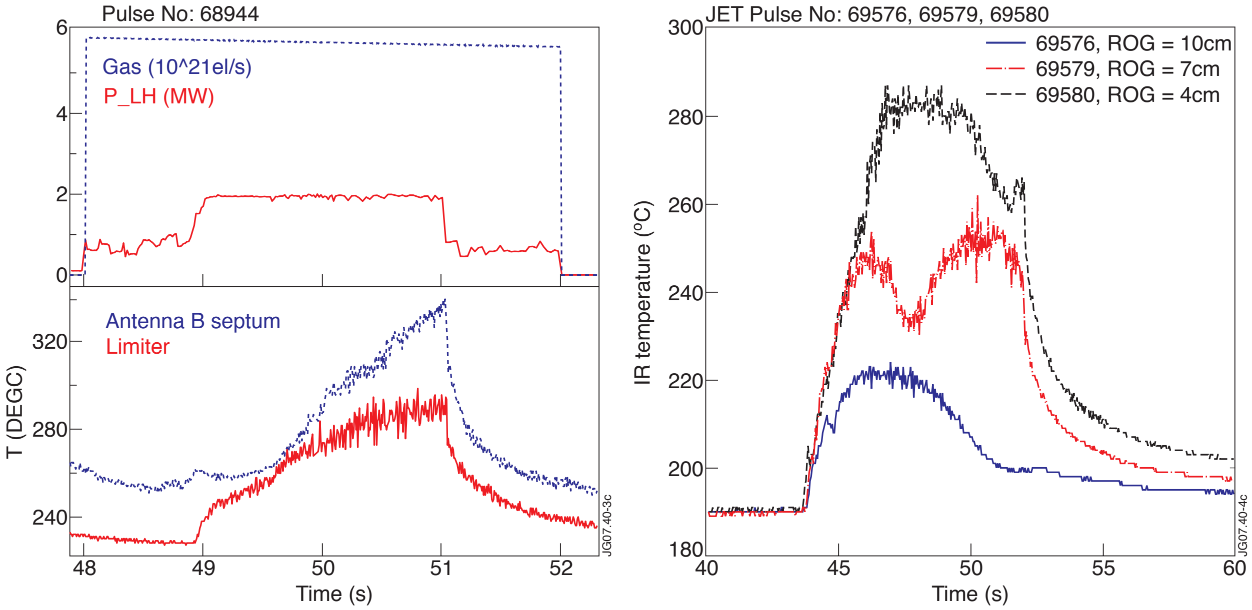

Figure 3: LH power (solid line) and gas level in top left frame and wall temperature on septum on Antenna B (dashed line) and Limiter (solid line) in the left bottom frame. Right frame shows wall temperature dependence on plasma – wall distance (ROG) as measured on the limiter.