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ABSTRACT

LHCD coupling deteriorates when the system is pulsed with ICRF antennas magnetically connected to the launcher. This has been attributed to the density modifications by the RF sheaths. RCs dependencies are investigated and shown consistent with the sheath physics. Near launcher gas puff has been used to reduce the RCs and LHCD power trips. Statistical analysis of the data is summarised and the undertaken modelling activities are outlined.

INTRODUCTION

Understanding the effect of the Ion Cyclotron Range of Frequencies (ICRF) generated sheaths on the Lower Hybrid (LH) wave coupling is an important issue regarding (i) the optimisation of the performance of the LHCD system at JET and (ii) the decision on the LHCD port allocation for ITER and the related implications. JET features both heating systems and the forthcoming installation of the ITER-like antenna makes it unique device for studying their mutual operation in ITER relevant conditions.

The LHCD launcher at JET is situated near the ICRF antenna B and magnetically connected to it and to antenna A in some cases, Fig. 1. The former was rarely pulsed at the same time with LHCD before 2004 due to its detrimental effect on the LH coupling demonstrated in experiments [1] which also suggested near launcher gas injection of CD_4 as a remedy. Both antennas A and B are powered by generators B since 2005 and turning them off imposes severe power limitation for experiments requiring LHCD and ICRF power. This motivated experiments in 2006, to continue to investigate the effect of ICRF antennas B and A on LHCD coupling, and try to improve it. Presently both systems are routinely used together.

The RF sheaths are related to the interactions of RF field with the surrounding materials as a result of which rectified sheath potential builds up at the boundaries of the near surfaces, e.g. Faraday Screen, septum, limiters, etc. A comprehensive analysis of the RF sheaths at JET is presented in [2] where sheath potential is shown to scale with the coupled RF power. Its spatial gradients gives rise to $\boldsymbol{E}\times\boldsymbol{B}$ drift and so called RF sheath induced convection. Convective cells models [3] have shown that SOL density decreases and its profile flattens as a result of the RF induced convection. Density pump out effect in the front of ICRF antennas was observed experimentally in TFTR [4] and in Tore Supra (TS) [5] and it has been shown that this phenomena is compatible with the drifts due to RF sheath.

EXPERIMENTAL RESULTS

LH wave coupling is investigated by analysing the dependencies of the LH Reflection Coefficients (RCs) on rows #1 to 6 on selected RF and plasma parameters: power from antenna A and B, P_{antA} and P_{antB}, stripes B12, P_{B12}, and B34, RF antenna phasings, launcher position l_{pos} and edge confinement mode. The plasma density increase after RF switch on does not allow for RC comparison with zero RF power.

Experiments in which antenna A and B were pulsed separately have shown that the former does not affect the coupling of the upper part of the LH grill in the configurations investigated. The RCs on the bottom three rows increase, Fig. 2a, with PantA and the coupling on row #4 is worse with antenna A compared to B. Antenna's B stripes 3 and 4 (B34) are closer to LHCD launcher, Fig. 2b, and when pulsed separately from stripes 1 and 2 (B12) affect the coupling on all rows. The power from B12 does not affect the RCs on rows # 3, 4 and 5 for l_{pos}=-0.5cm, while the increase of RCs with P_{B12} is significant on rows # 2 and 6, Fig. 2b. In general the LHCD coupling deteriorates with P_{antB} in both L- and H-modes, Fig. 3. In L-mode, the effect is lesser pronounced: only RCs on rows #2 and 3 increase slightly with the RF power while the bottom rows show no change, Fig. 3a. The increase of P_{antB} from 0.6MW to 1.5MW in H-mode results in worse coupling on almost all rows, Fig. 3b. Under certain conditions it has been observed that the RCs measured from certain klystrons decrease with ICRH power, P_{ICRH}. This effect is better pronounced on the bottom rows and it suggests that local effects may play a role in the SOL density modifications and the latter is neither poloidally nor toroidally symmetric. The analysis of the data has shown that with launcher close to plasma, l_{pos}~-0.5cm, RF power has no or little effect on RCs, while with retracted launcher, $|l_{pos}|$>1.5cm, the coupling deteriorates with P_{antB}. The LHCD coupling is worst when antenna B is powered in $-\pi/2$ or monopole phasing then dipole and $+\pi/2$, Fig. 4, which are mainly used at JET. These observations and dependencies are all consistent with the RF sheaths physics.

Gas injection of CD_4 from the near gas pipe GIM6 improved the LHCD coupling when pulsing with ICRF antenna B [1]. However this was not sufficient and regular use of both systems was avoided until 2006. The experiments, which follow after that, were using mainly D_2. Even small amount of D_2 has improving effect of bottom three rows, Fig. 3 and 5, and further increase of the gas puff rate improves the coupling on rows # 2 and 3 as well. However, RCs on rows # 5 and 6 slightly increase with the gas injection rate, Fig. 5, in both L and H-mode plasma. D2 was later routinely used in experiments, which required power from LHCD and ICRF antennas A and B and a record of 3.5MW of LHCD power was coupled in H-mode under similar conditions.

The LHCD coupling was studied by means of statistical analysis. The advantage of this method is that it covers large number of parameters varying over broad ranges. RCs are fitted to a power function of the following parameters: plasma limiter distance, r_{ROG}, safety factor at the edge q_{95}, which accounts for the edge connection lengths and density thickness, P_{AntB} (antenna B was pulsed together with A), LH power P_{LH}, line averaged plasma density $\overline{n}_e$ measured near the edge, and H factor H_{89}, which accounts for the edge confinement. The launcher position l_{pos} and GIM6 gas injection rate are correlated, only l_{pos}=-0.5cm no gas cases were used in the analysis.

The regression coefficients show correctly the main features of the LHCD coupling: improvement with n_e and q_{95} and worsening with r_{ROG} and H_{89}. Regarding the effect of the RF power on the LHCD coupling the analysis of the dipole antenna phasing shows no dependence for rows # 2, 3 and 4, coupling improvement with P_{AntB} for row #1 and worsening for rows #5 and 6. This can be explained with the fact that at l_{pos}=-0.5cm the plasma is close to the launcher at its central part and the ICRF power does not change significantly this. However, as the bottom rows are usually farther from the plasma the density pump out by the ICRF is expecting to have a detrimental effects on the coupling.

OUTLINE OF THE FUTURE WORK

The new ITER-like antenna will imply studies on its effect on the LHCD coupling. Field line mapping calculations will relate the changes of the RCs to specific ICRF antennas regions, which can be further investigated by means of Infra Red camera imaging. Modelling of JET ICRF antennas near field will identify locations susceptible to develop RF sheaths. SOL transport code can be further used to model the density modifications by ICRF sheaths.

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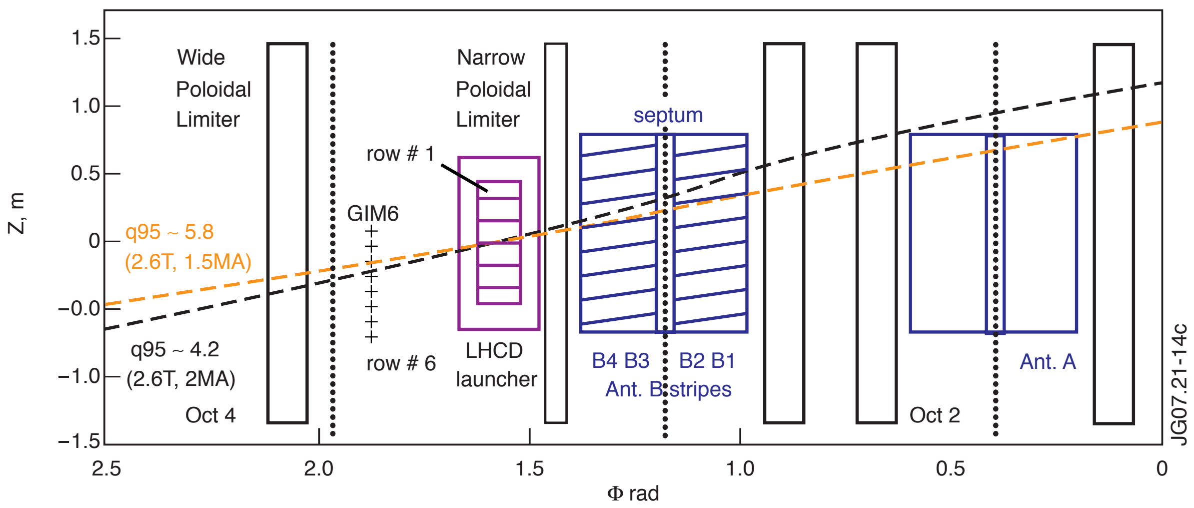

Figure 1. Φ-Z view of the LH launcher and near ICRF antennas.

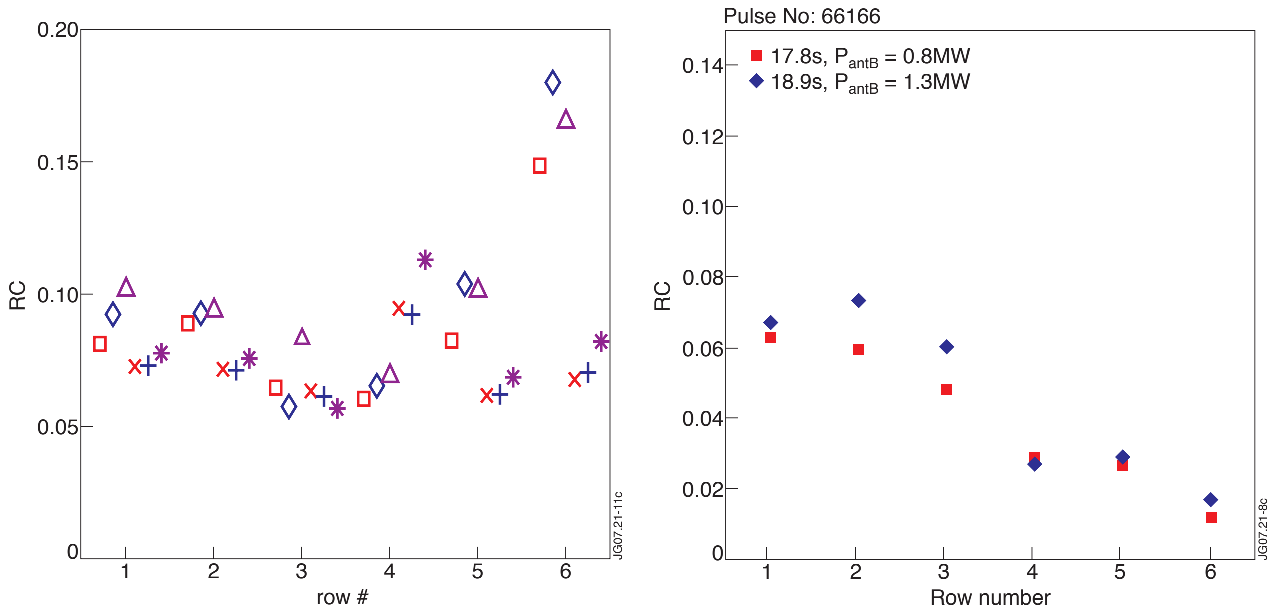

Figure 2: Effect of RF antenna A and B (a) and stripes B12 and B34 (b) on LHCD coupling. L-mode, 2.6T, 2MA, no gas puff and dipole phasing were used.

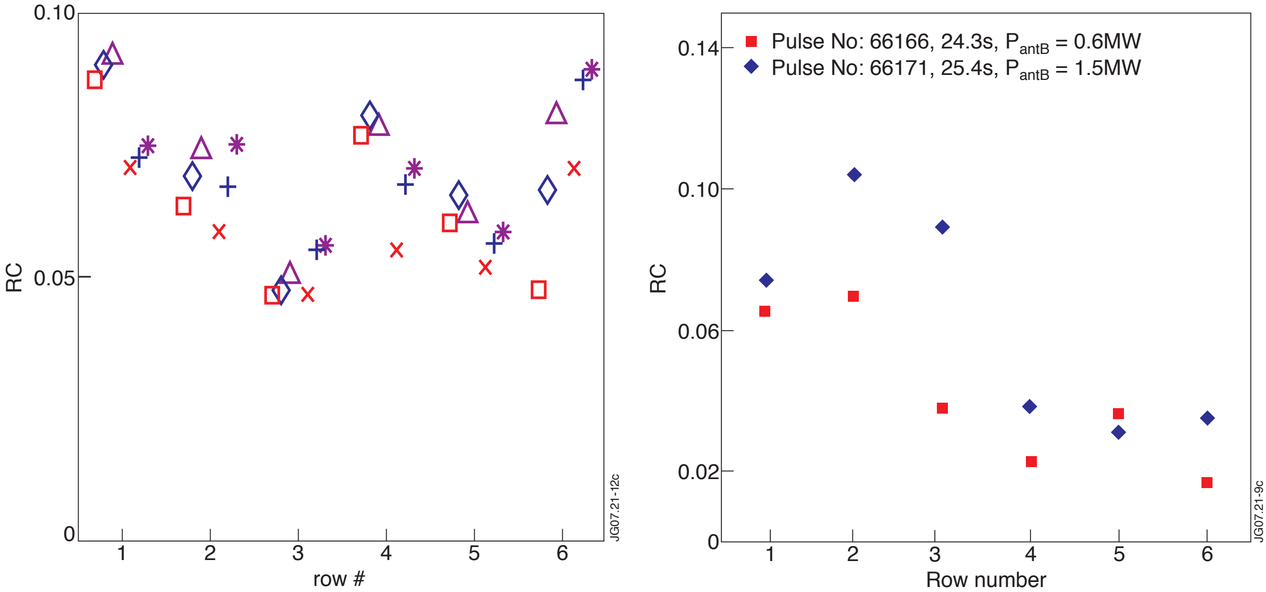

Figure 3: LH coupling at different P_{antB} in L (a) and H-mode (b) plasma. 2.6T, 1.5MA, D_2 rate G06R~4.5e21el/s, ant. B+A in +π/2 phasing, l_{pos}=-2.5cm in (a) and –3cm in (b).

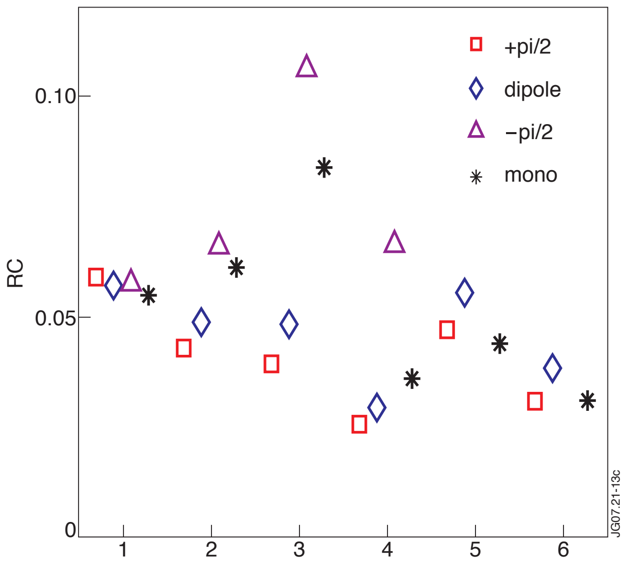

Figure 4: RCs on rows #1 to 6 for four different phasings of ICRF L-mode plasma, 2.6T, 1.5MA, P_{antB} ~ 0.8MW (~0.6MW in mono), l_{pos} ~ -2.5cm, and D_2 gas, G06R ~ 6.5e21 el/s, was used.

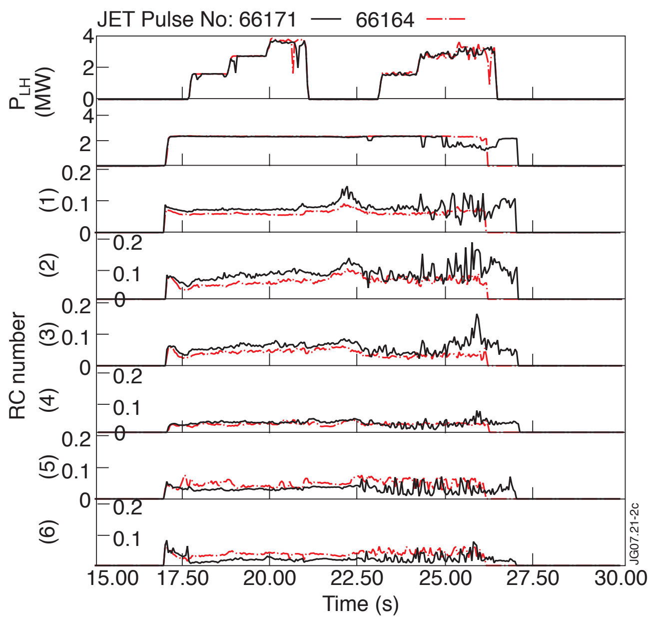

Figure 5: Time traces of two similar JET pulses with low (blue) and high (red) D2 gas puff rate. ant. B+A in +π/2 phasing and l_{pos}=-2.5cm in L and -3cm in H-mode.