LHCD operation with ILW at JET

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1. Introduction

ITER is designed to operate with beryllium (*Be*) main wall and tungsten (*W*) divertor in order to comply with the requirements for low level of fuel retention. The necessity for better understanding of the plasma surface interactions and the underlying new physics initiated a project on installation of a new ITER Like Wall (ILW) at JET [1]. Although currently not planned, a Lower Hybrid Current Drive (LHCD) system is still under consideration for ITER and this paper discusses important aspects of the performance of LHCD with ILW at JET for power levels up to 2.5MW.

2. Impurities associated with ILW

Impurity release and accumulation during the auxiliary heating has been regarded as an essential issue for JET operations with the new metallic wall. Details on the LHCD impact are not fully studied yet; however, an assessment of the increase of the impurities radiation due to LHCD has been carried out by analysing *Be* and *W* spectral line intensities, figure 1.

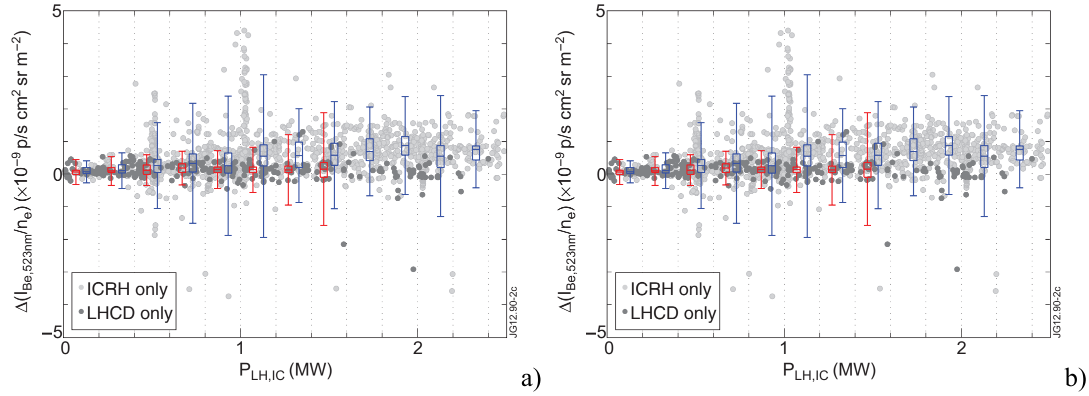


Figure 1: *Impurities generation related to LHCD (dark gray dots) and ICRH (gray dots). Increase of normalized line emission from Be (baseline 523nm (a)) and W (VUV feature centred at 18nm (b)) is provided versus applied LHCD and ICRH power. Data is also presented statistically as points are binned in 0.2MW intervals and boxplots represent lower, upper quartile and median while the whiskers show 98% of the observations for LHCD (red) and ICRH (blue) only pulses.*

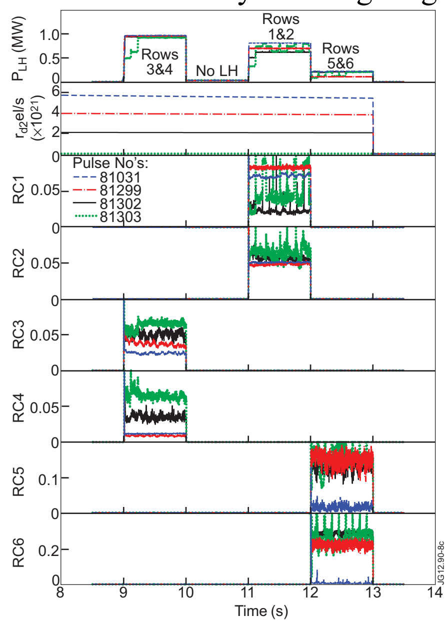
Data from *Be* baseline, which is observed predominantly at the edge, and *W* feature, coming from the hot plasma interior with temperature of about 1.5-2keV, were collected and averaged over steady-state time intervals during LHCD conditioning pulses. The essential plasma parameters (configuration, density, temperature and fuelling rate) in the LHCD database do

* *See the Appendix of F. Romanelli et al., Proceedings of the 23rd IAEA Fusion Energy Conference 2010, Daejeon, Korea"*

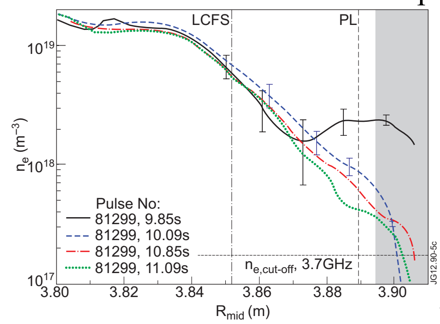
not vary significantly, while the processes involved in impurity generation and transport are not accounted for. The intensities are normalised to the line integrated density and subtracted from a non LHCD reference which is taken shortly before the system is turned on. The results in figure 1 are, therefore, interpreted as an estimate of the increase of impurity concentration due to LHCD heating power. It was found that for up to 2.5MW there is only small increase in *Be* and *W* in LHCD only experiments. ICRH data are provided for comparison only as the processes involved are of different nature. Nevertheless the two heating sources have similar dependences regarding *Be*, while LHCD related *W* data are somewhat lower.

3. Coupling studies

LHCD coupling in conditions with ILW. Due to different conditions (configuration, plasma-launcher distance, electron density and gas puff rates) being used before ILW installation and during present experimental campaigns a comprehensive conclusion on the impact of ILW on the LH wave coupling is difficult to be drawn. However, after cross-checking the Reflection Coefficients (RCs) on all six rows of the LH launcher for pulses in which these parameters are similar it was found that the coupling is not degraded and the negative impact of the reduced recycling can be compensated by injection of *D2* from dedicated gas introduction module near the LHCD launcher. Gas injection rates were scanned during plasma conditioning pulses in which rows 1&2, 3&4 and 5&6 were pulsed separately, figure 2a, and it was found that rates of about 4×10^{21}el/s provide good coupling for all rows in L-mode conditions. The bottom two rows, which are usually farther from plasma than the middle of the launcher, benefit substantially from higher gas rates, i.e. 6×10^{21}el/s for which RC5&6 drop below 5%.



a)



b)

Figure 2: RCs of the top (RC1&2), middle (RC3&4) and bottom (RC5&6) rows of LH launcher for four values of gas puff rate (r_{d2}) from dedicated gas introduction module (a). Li beam density profiles in log scale for 2.7T/2.45MA L-mode pulse #81299 (b). At time slice 9.85s when middle of grill, which is magnetically connected to Li-beam, is energised density increases between R_{mid}~3.87m and 3.89m. Later when LHCD power was turned off (10.09s, 10.85s) or top rows, which are not connected to Li-beam, are pulsed (11.09s), density profiles are not affected. Private SOL region is shadowed and separatrix (LCFS) and poloidal limiter (PL) projections at the midplane radius are shown.

SOL density measurements. Measurements of the Scrape-off Layer (SOL) density were used to assess the modifications due to LHCD. For plasmas with 2.7T/2.45MA the middle of the launcher, i.e. rows 3&4, is magnetically connected to Li-beam diagnostic. It was observed that SOL density increases locally during the LHCD phase thus improving the coupling. The observed effects are poloidally inhomogeneous, i.e. only the flux tubes in front of the powered rows show changes in density, figure 2. It was found that SOL density increases with increase of the puff rate from the dedicated gas valve and with coupled LHCD power.

4. Protection against arcs and hotspots

Observation of arcs via dedicated visible camera. A number of protection issues were addressed during the LHCD operation with ILW at JET [2]. Arcs are potentially the most dangerous events related to LHCD as they may not only damage the launcher but they are also related to large impurity influx of iron (*Fe*) which sometimes causes plasma disruptions. Arcs are now monitored by a new dedicated visible camera viewing the whole LH grill with sufficient resolution to identify on which part of the LH grill the arc is taking place, figure 3. For the first time at JET it was observed that if a localised arc is not extinguished fast enough by the protection system it can propagate along the grill mouth thus covering much larger region, which might result in substantial damage to the launcher.

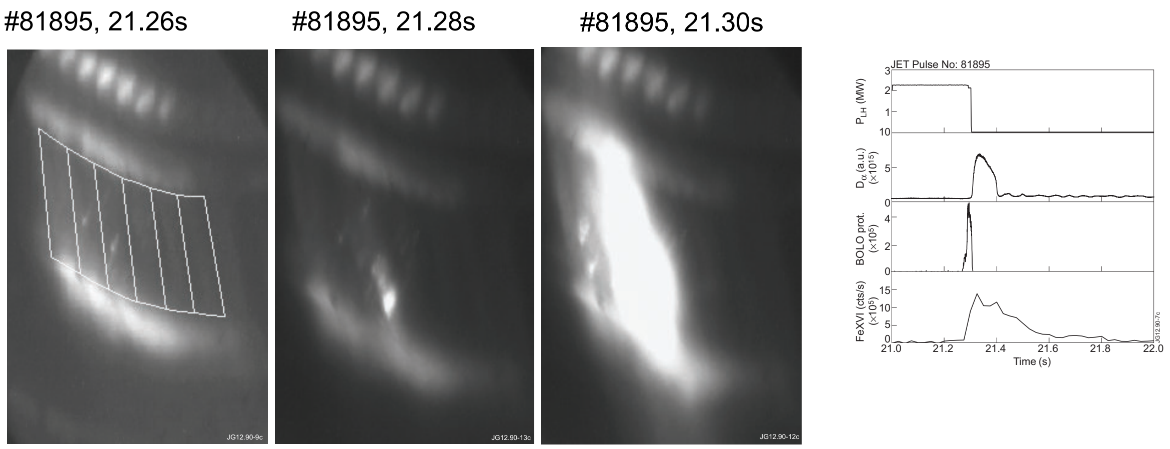


Figure 3: Arc seen on the visible camera in three consecutive frames showing how arc develops into a flare in front of rows 2&3, JET pulse #81895, 21.26s-21.30s. The six rows of the LH grill are indicated in the first picture. Pictures are rotated 90° anti-clockwise, so that top two rows 1&2 are on the left, while bottom rows 5&6 are on the right. The time traces of the LHCD power, D_α signal, bolometer protection and FeXVI line are shown on the right.

LH grill heating and first wall hotspots. Although not fully calibrated yet, images from an IR camera were used for the first time to assess the distribution of the heat on the launcher during LH operation. Initial observations, figure 4(a), show that the grill is non-uniformly heated when LH power is applied. There is no clear indication that the hottest areas of the grill are in fact the most damaged waveguides.

Although hot spots due to LHCD are noticed, up to now no detrimental temperature increase has been observed for pulses up to 5s. An illustrative example is shown in figure 4(b,c) where the temperature measured on the top tile of the outer divertor region reaches about 870°C. The fast changes of the temperature with applied modulated LH power indicate that only surface effects are seen as no bulk heating is compatible with this sort of time evolution.

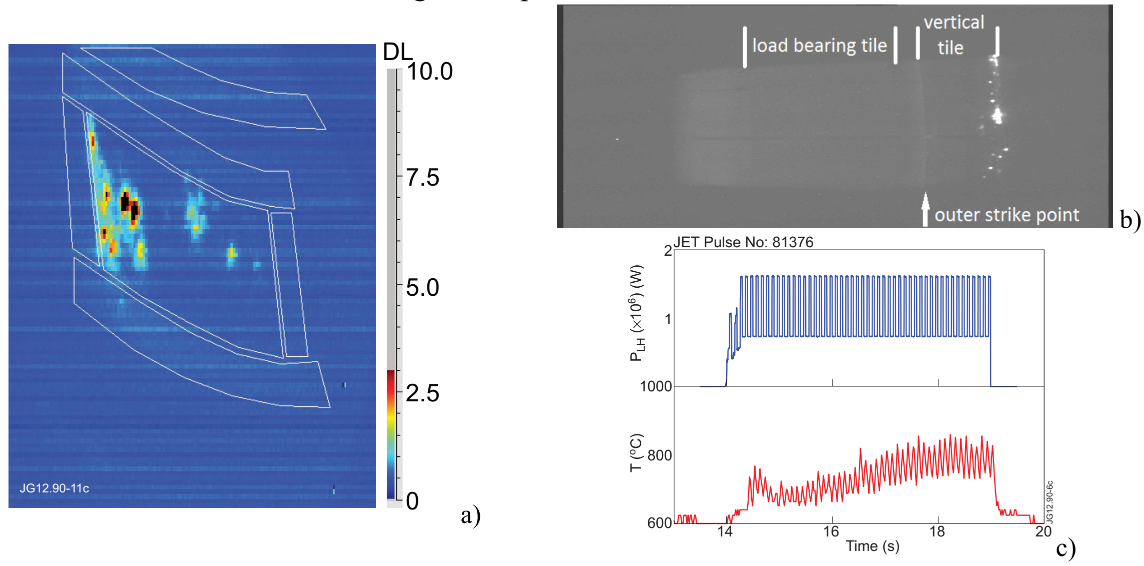


Figure 4: *IR camera image of LH launcher (in arbitrary units) showing that the grill is heated irregularly when placed closer to the plasma,* l_{pos}*~0.013m, during JET pulse, #82943, 21.57s with* P_{LH}*~1.4MW (a). Bright spots on top of vertical tile in the outer divertor during modulated LHCD experiment, #81377, 19.32s (b). Increase of the temperature on the vertical divertor tile due to heating of surface layer caused by LHCD(c).*

5. Summary and future prospects

Overall a relatively trouble-free operation of the LHCD system up to 2.5MW of coupled microwave power in L-mode plasma was achieved with no indication that the power can not be increased further. A project to implement a real-time protection based on the visible camera providing sufficient resolution and fast response to treat only the arcing klystrons has been started. It is believed that with this protection in place arcs can be stopped quickly enough to avoid the potentially dangerous consequences of damage to the launcher and plasma disruption. Once fully calibrated pyrometers and the IR camera will be used to protect against and study in details the parasitic loss of LH power in the SOL.

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