EFDA–JET–CP(13)02/04

K.K. Kirov, Yu. Baranov, E. Barbato, M. Brix, G. Corrigan, A. Ekedahl,
M. Goniche, J. Mailloux, V. Petrzilka, F. Rimini, M. Stamp
and JET EFDA contributors

Overview of LH Experiments in JET with an ITER-Like Wall

Overview of LH Experiments in JET with an ITER-Like Wall

K.K. Kirov[1], Yu. Baranov[1], E. Barbato[2], M. Brix[1], G. Corrigan[1], A. Ekedahl[3],
M. Goniche[3], J. Mailloux[1], V. Petrzilka[4], F. Rimini[1], M. Stamp[1]
and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]EURATOM-CCFE Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK
[2]Associazione EURATOM-ENEA sulla Fusione, C.R. Frascati, Roma, Italy
[3]CEA, IRFM, F-13108 Saint Paul-lez-Durance, France
[4]Association EURATOM-IPP.CR, IPP AS CR, 182 21 Praha 8, Czech Republic
** See annex of F. Romanelli et al, "Overview of JET Results",*
(24th IAEA Fusion Energy Conference, San Diego, USA (2012)).

Preprint of Paper to be submitted for publication in Proceedings of the
20th Topical Conference on Radio Frequency Power in Plasmas, Sorrento, Italy.
25th June 2013 - 28th June 2013

ABSTRACT

An overview of the recent results of Lower Hybrid (LH) experiments at JET with the ITER-like wall (ILW) is presented. Topics relevant to LH wave coupling are addressed as well as issues related to ILW and LH system protections. LH wave coupling was studied in conditions determined by ILW recycling and operational constraints. It was concluded that LH wave coupling was not significantly affected and the pre-ILW performance could be recovered after optimising the launcher position and local gas puffing. SOL density measurements were performed using a Li-beam diagnostic. Dependencies on the D_2 injection rate from the dedicated gas valve, the LH power and the LH launcher position were analysed. SOL density modifications due to LH were modelled by the EDGE2D code assuming SOL heating by collisional dissipation of the LH wave and/or possible ExB drifts in the SOL. The simulations matched reasonably well the measured SOL profiles. Observations of arcs and hotspots with visible and IR cameras viewing the LH launcher are presented.

INTRODUCTION

Since 2011, JET has operated with a new wall which is commonly referred to as the ITER Like Wall. It is designed to replicate ITER Plasma Facing Components (PFC) with outboard Poloidal Limiters (PLs) and inner guard limiters made of *Be*, while the thermal load bearing divertor consists of *W* coated *C* tiles and bulk *W* tile assemblies [1]. JET plasma parameters were affected by: (*i*) the operating limits of the new materials; (*ii*) the fuel recycling and (*iii*) the impurities related to the new PFC. The impact of these contributions on the performance of the auxiliary heating systems and the main achievements by these were reviewed in [2]. The main aspects of the operation of the Lower Hybrid (LH) system, which is also under consideration for ITER, under the new conditions associated with ILW were also studied and reported in [3]. This paper provides further details on the LH wave coupling studies in conditions with ILW, analysis of the SOL density modifications and relevant modelling. Important conclusions based on observations of arcs and hotspots in front of the LH launcher are reported as well.

1. LH WAVE COUPLING IN CONDITIONS WITH THE NEW WALL.

SOL parameters have been affected by the new PFC and the operational constraints related, as were the LH coupling conditions. In general, a problematic LH wave coupling was envisaged with the new wall due to the lower recycling expected with all metallic PFC and higher pedestal density. The latter is due to the larger amount of gas injection used with ILW – a constraint which was initially driven by the request to reduce the sputtering yield of PFC.

Initial observations indicated that with the launcher retracted behind the protective narrow PL, nPL, i.e. for launcher position $l_{pos} < 0$m, the Reflection Coefficients (RCs) are large and gas injection of D_2 from a dedicated gas valve is needed in order to maintain a good performance of the system. A more detailed comparison of LH wave coupling conditions was carried out for $l_{pos} > 0$m after cross-checking the averaged RCs for pulses in which SOL conditions and plasma parameters are similar. In the case when no gas from a dedicated valve was used, and for launcher position between l_{pos} +0.001m and l_{pos} +0.006m, it was found that the RCs on the top and at the middle of the launcher are approximately the same as with the old *C* wall (CW) indicating that for the upper part of the grill coupling is not affected. The bottom two rows, 5&6, however, had higher RCs with ILW compared to CW. Adding gas puff from the dedicated gas valve, a well known remedy to lower the RCs, improved the coupling on the bottom rows as well.

In the process of optimising the performance of the LH system, the gas injection rates from a dedicated gas injection valve were scanned and it was found that coupling improves on all rows with injection rate. An example with $l_{pos} = 0.000$m is shown in figure 1a, where RCs of rows 1&2, 3&4, and 5&6, are shown for four different values of D_2 gas injection rates, i.e. 0, 2×10^{21}, 4×10^{21}, 6×10^{21} el/s as provided in the legend. Power waveforms, total gas puff rates and line-integrated electron density are also shown. Central and pedestal densities of these pulses were relatively similar, n_{e0}~3.2×10^{19} m^3 and $n_{e,ped}$~1.6×10^{19} m^3. For the middle rows, 3&4, with RC3&4, the coupling is good, as RCs<0.08, even without gas. Higher rates of injection further reduce the RCs on these rows. The top two rows, 1&2, need rates of about 4×10^{21}el/s to achieve a reasonable coupling and to stop being tripped by the protection system, based on the imbalance in the reflected RF power. In contrast, the bottom rows, 5&6, show bad coupling, RCs>0.12, for lower gas rates and good coupling is only achieved at maximum gas injection rate used in the experiments, i.e. ~6×10^{21}el/s.

2. SOL DENSITY MEASUREMENTS AND EDGE2D MODELLING

Measurements of the SOL density were used to assess the changes in front of the launcher due to applied LH power. For plasmas with 2.7T/2.45MA the middle of the launcher, i.e. rows 3&4, is magnetically connected to a Li-beam diagnostic. It was observed that the 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 1a bottom graph and figure 1b). It was found that SOL density increases with increase of the puff rate from the dedicated gas valve (figure 1b) and with coupled LHCD power.

The observed density changes were modelled by means of the EDGE2D code. Geometrical and SOL-related parameters were all input into the code in agreement with the available experimental data. In the simulations the gas was injected from poloidal locations corresponding to the dedicated gas injection valve location. It was assumed that density modifications in the SOL with LH power are due to enhancement in the ionisation rates caused by parasitical heating of the SOL. The RF power losses due to collisional dissipation and parasitic fast electron generation in the SOL are introduced in the code as a fixed source in electron density transport equation. The modelling results in which SOL heating about 2cm in front of the launcher is assumed are shown in figure 1c. The changes in SOL profile with LH power were best simulated assuming about 10kW of LH power absorbed in the SOL.

The calculations are more consistent with the experimental results in the cases when gas from dedicated valve was used; however, in the simulations about twice smaller gas puff rate was needed to reproduce the changes in SOL density with LH power. An increase in dissipated power was needed in order to reproduce the density changes when launcher is moved forward in front of the limiter. Eventual impact by SOL drifts was studied as well. Parasitically absorbed LH power generates fast electrons in the SOL, which in turn can significantly influence SOL potentials and induce ExB drifts. Preliminary results of EDGE2D simulation, which includes the possible effect of ExB drifts are shown in figure 1d. It seems that in this case the impact of the drifts is small and in a negative direction relative to the local density changes in front of the launcher. The LH power loses in the SOL in this case were assessed to be of the order of 16.3kW. From the simulations it can be concluded that only a few percent (maximum of about 5-6%) of the launched power is absorbed by the SOL plasma in the magnetic flux tubes in front of the LH grill.

3. VISIBLE AND IR CAMERA OBSERVATIONS

For the first time at JET the dynamics of arc development have been observed (figure 2a) employing a visible camera. It has been seen that if a localised arc is not extinguished fast enough by the existing protection system, (based on the reflected power imbalance and on the impurity radiation) it can propagate along the grill mouth thus covering a much larger area, which might result in substantial damage to the launcher or, in rare cases, in a plasma disruption.

The camera has sufficient resolution to determine on which part of the grill arc is taking place and based on this a new real-time protection acting only on the arcing klystrons is being developed as part of JET protection system.

Images from an Infra Red (IR) camera with a dedicated view in front of the LH launcher were used for the first time to assess the distribution of the heat on the launcher mouth during LHCD-only operation. The camera was not calibrated in time for JET campaigns and so absolute temperature measurements were not available. However, visual inspection and investigation of the heat load distributions and relative temperature changes could be carried out. The initial observations, figure 2b, show that the grill was irregularly heated when the launcher was moved closer to the plasma and LHCD power applied. Provided that the launcher has been melted predominantly on the left side and also at the top left corner there is no clear indication that the hottest areas of the grill were the most damaged multijunctions.

Interestingly, the coupled RF power and the non-powered sections of the launcher do not seem to have a strong impact on the pattern of the hot areas. Attention should be paid to the bottom-right hotspots (figure 2b, the bright box in the middle of rows 5&6) which are in the non-powered section of the grill. This indicates that harmful plasma-launcher interaction can occur in front of non-energised multijunctions as well. The investigation will further benefit from proper IR camera calibration and the analysis is planned to be completed by density, gas injection rates and LHCD power scans.

SUMMARY AND CONCLUSIONS

Overall, a relatively trouble-free operation of the LH system in the new ILW for up to 2.5MW of coupled microwave power in L-mode plasma for time duration of up to 5s was achieved. Impurity generation and production in all LH only pulses was analysed and found negligible [3]. LH coupling is not degraded with installation of ILW.

Improved Li-beam measurements allowed for SOL density measurements and first systematic study of the impact of LH on the SOL parameters. Gas injection rates, plasma density and configuration and launcher position were all scanned in optimising the coupling, while the relevant changes to the SOL parameters were documented by Li-beam measurements.

First observation of arcs in front of LH grill is reported. Arcs are not always stopped by existing protection and when not extinguished in time they seem to propagate along the row. A proposal to implement a new real-time protection acting only on the arcing klystrons is being considered as part of JET protection system and a project on its implementation 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.

ACKNOWLEDGEMENTS

This work, supported by the European Communities under the contract of Association between EURATOM and CCFE, was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission. This work was also part-funded by the RCUK Energy Programme under grant EP/I501045.

REFERENCES

[1]. G.G.F. Matthews et al 2011 Physica Scripta 2011 014001 doi:10.1088/0031-8949/2011/T145/014001
[2]. M. Mayoral et al., Proceedings of the 24th IAEA FEC San Diego, USA 8-13 October 2012, IAEA-CN-197, EX/4-3
[3]. K. Kirov et al, 2013, submitted to Plasma Physics and Controlled Fusion

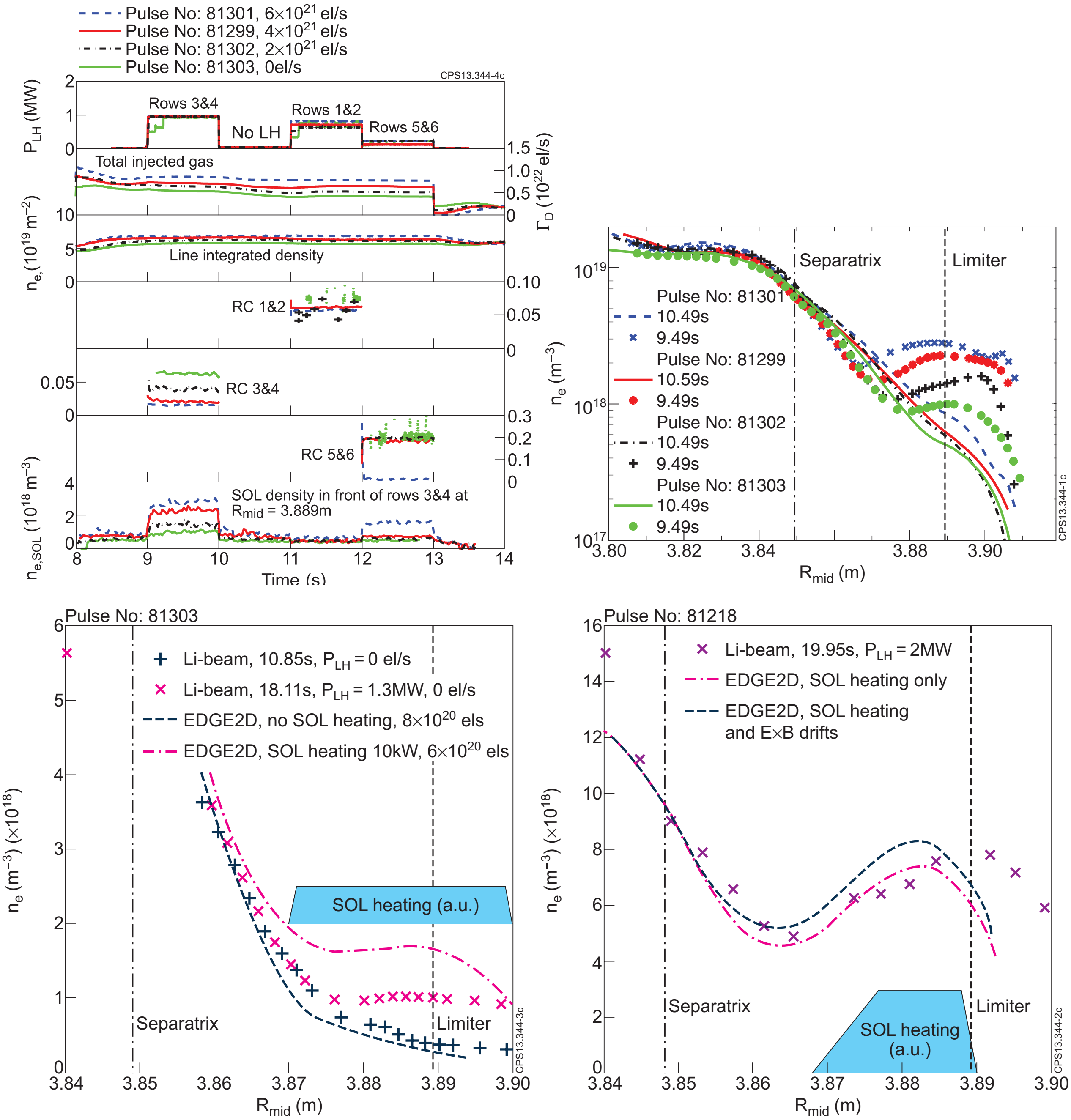
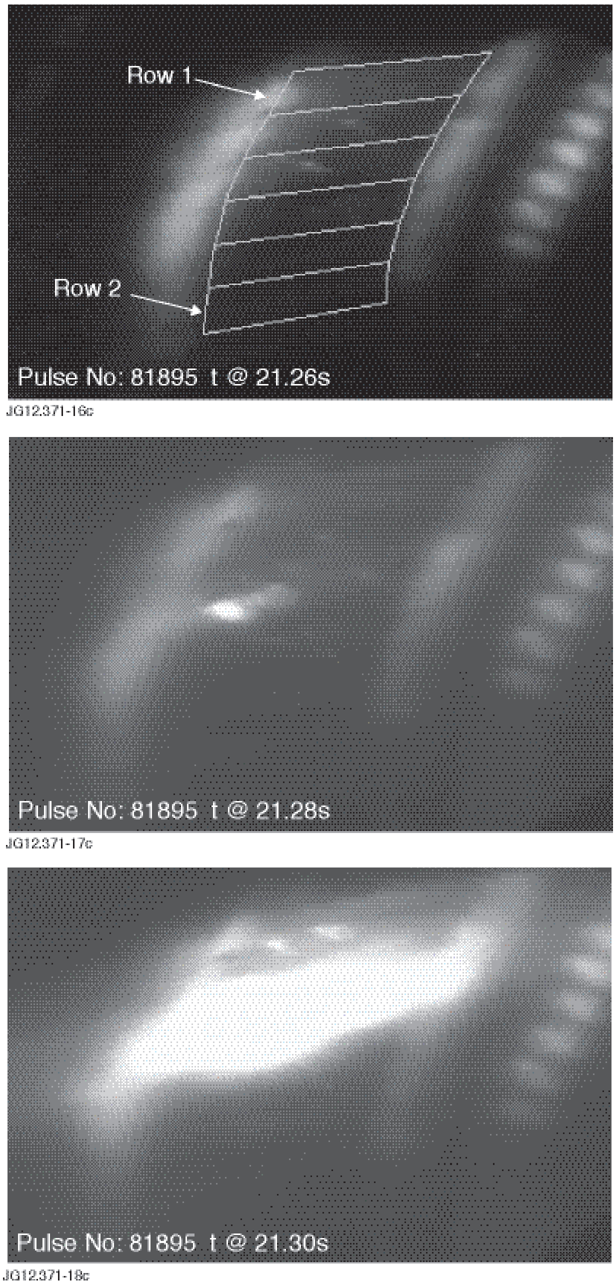


Figure 1: (a) Time traces of LH power, total gas injection, line integrated electron density, RCs on rows 1&2, 3&4 and 5&6 and SOL density in front of rows 3&4 at midplane position of PL, $R_{mid} = 3.889m$, by Li-beam. D_2 gas injection rates from dedicated gas injection valve in these 2.7T/2.45MA JET pulses with $l_{pos} = 0.000m$ are given in the legend. (b) SOL profiles with (symbols) and without (lines) LH power for different gas injection rates for the pulses shown in (a). Measured Li-beam SOL density profiles (symbols) without and with LH power for Pulse No: 81303 are provided in (c) together with EDGE2D modelling results (lines) assuming zero and 30kW of parasitic LH heating in SOL between $R_{mid} = 3.87m$ and $R_{mid} = 3.90m$ (bright rectangle). LH power and the gas injection rates – as used in the model and from dedicated valve – are given in the legend. Experimental data (symbols) for Pulse No:82218 with launcher position at l_{pos}~-0.005m and gas injection rate from dedicated vale of $7×10^{21}$ el/s and EDGE2D simulations without (dashed line) and with ExB (dashed-dotted line) drifts are shown in (d)

(a)



(b)

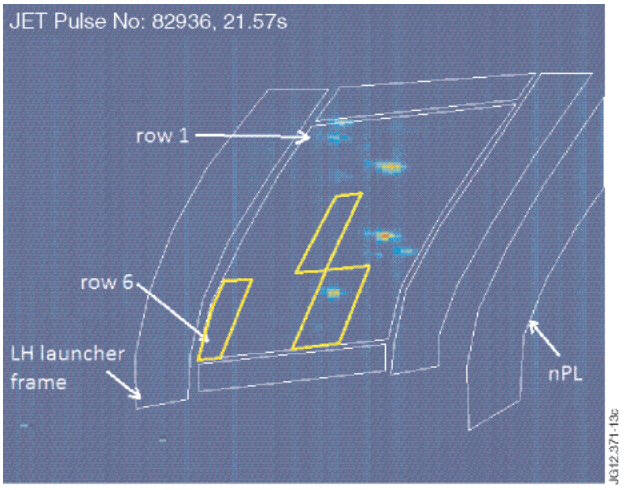


Figure 2: (a) Arc seen on the visible LH camera in three consecutive frames, Pulse No: 81895, 21.26s, 21.28s and 21.30s, showing how an arc develops into a flare in front of rows 2&3. (b) IR LHCD camera images of the launcher showing hottest areas of the grill for 2.4T/2MA JET Pulse No: 82936, 21.57s with $P_{LH} \approx 1.6MW$ *from 18s to 23s and* $l_{pos} \approx 0.008m$. *The LH launcher frame,* n_{PL} *and approximate positions of rows 1 and 6 are indicated by arrows and thin white lines. The approximate positions of the non energised sections of the grill are show by thick bright boxes, while the rest of the klystrons are powered with »85kW.*