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LHCD Experiments on HL-2A and EAST towards High Confinement and Long Pulse Operation

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This paper gives an overview of the results obtained within the collaboration between CEA/IRFM and the institutes SWIP and ASIPP, respectively, in the area of Lower Hybrid Current Drive (LHCD).

In HL-2A [1], a 3.7 GHz LHCD system consisting of four klystrons and passive-active multijunction (PAM) launcher [2], has been successfully brought into operation and used in H-mode experiments [3]. Coupling LH power during ELMs has thus been demonstrated with a PAM launcher for the first time. In the scenario chosen (I_P = 160 kA, B_T = 1.4 T, $n_e \sim 2\times10^{19}$ m^{-3}), H-mode was triggered when additional LH power (200 – 500 kW) was applied in combination with 700 – 800 kW NBI power. The LH power was coupled at large plasma - launcher gap, often larger than 10 cm. Local gas injection near the launcher was mandatory for obtaining good coupling of the LH wave at such large gaps. Large variation in reflection coefficient over the poloidal rows was observed, leading to an average reflection coefficient larger than that predicted by the ALOHA code [4]. In H-mode plasmas at high density and LH power > 300 kW, reduction of the ELM amplitude and increase in ELM frequency were observed, suggesting that the LH power has a mitigating effect on the ELMs, as already observed in EAST.

Following a number of improvements on the plasma control system and on the LHCD system, the subsequent experiments have allowed further progress in HL-2A, with coupled LH power reaching 900 kW in H-mode and 1 MW in L-mode.

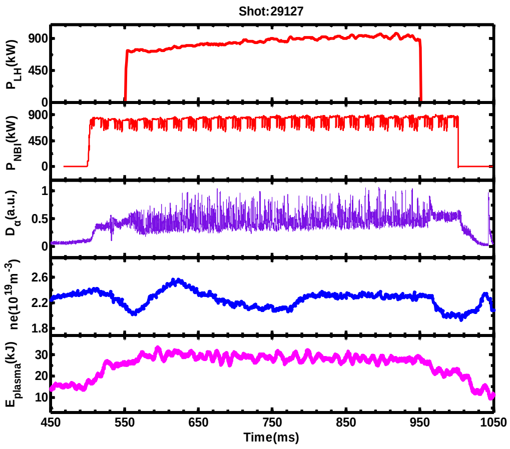

Figure 1. H-mode triggered and sustained by LHCD in NBI-heated plasma in HL-2A.

EAST [5] disposes of two LHCD launchers operating at two different frequencies (2.45 GHz and 4.6 GHz) [6]. Experiments have been carried out to optimizing the LH wave coupling and the CD efficiency in view of long pulse H-mode operation. The CD efficiency of the 4.6 GHz launcher was studied in different plasma configurations (Upper Single Null vs Lower Single Null). The non-thermal ECE signal was found to be ~ 30% higher in the USN configuration and the bremsstrahlung from the fast electrons in the hard X-ray range was also higher in USN. The effect of the gas feed location on the LH wave coupling was investigated by comparing gas fuelling from high field side, low field side and upper divertor. No difference on the reflection coefficient (RC) was found. However, a significant decrease in RC was seen when the plasma was predominantly fuelled by SMBI, a method which is found to increase radial transport [7]. This increases the density in the far scrape-off layer, which is beneficial LH wave coupling.

The LHCD experiments were accompanied by C3PO/LUKE modelling [8]. Extended studies of various zero loop voltage discharges have confirmed the importance of the tail in the initial LH power spectrum for ray-tracing calculations. By adding a tail in the initial power spectrum, consistent results can be obtained with respect to the measured line-integrated hard X-ray profile, toroidal plasma current and internal inductance.

In view of long pulse H-mode scenarios, a series of H-mode experiments were conducted where all the heating power was provided by RF heating only (LHCD, ECRH and ICRH). H-modes were sustained in both USN (W divertor) and LSN (carbon divertor) configurations, with loop voltage as low as 50 mV. Easier access to H-mode was found when the $B\times\nabla B$ drift was directed towards the target. This was confirmed in both LSN and USN configurations.

In summary, these results also give valuable information in view of the exploitation of WEST, which has similar size to EAST, and which will use RF heating only (LHCD, ICRH) in a full W-environment.

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