Effect of LHCD on plasma current profile in EAST

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Abstract

Lower hybrid current drive (LHCD) is an important heating system for long pulse plasma with high performance in EAST. The effect of LHCD on current profile was summarized, including edge parameters, LH frequency, LH spectrum and plasma density. The role of parasitic effects of edge plasma on LHCD is studied and it can be mitigated by increasing source frequency or lowering recycling. Lower recycling and higher LH frequency are preferred for LHCD at higher density. Effect of LH spectrum and plasma density on LHCD suggests that the optimization is possible methods to control current profile. Results are encouraging that LHCD is essential for current profile control in reactor grade plasmas.

1. Introduction

Lower hybrid current drive (LHCD) has the attractive property of high off-axis (r/a ≈ 0.7) [1] current drive efficiency making this a useful technique for broadening the current density profile in order to create non-monotonic (shear reversed) profiles of the safety factor – q(r) with $q_{min} > 2$ and large shear reversal radius (r/a ≈ 0.7). The resulting profiles of safety factor allow access to improved energy confinement regimes with high fractions of the non-inductive bootstrap current (≈ 60-70%) [2], thus enabling achievement of the steady state Scenario-4 in the ITER device [3]. However, how to improve LHCD capability and control current profile at high density is an important issue to be solved before this application, which is mainly affected by collisional damping (CA) losses [4], parametric instability (PI) [5,6], scattering by density fluctuations (SDF) [7,8], and LH wave accessibility. In this paper, Effect of LHCD on plasma current profile in EAST will be summarized.

2. Parasitic Effect in edge region on LHCD

2.1Effect of edge parameters (2.45GHz) [9]

In order to explore the experimental condition for high CD efficiency at high density in EAST, experiments with 2.45GHz LHW were studied [9] with different wall conditions, i.e., poor and strong lithiumization. The effect of driven current is estimated by the count of hard X-ray rate (60keV~200keV) normalized by the injected LHW power, which is proportional to current driven efficiency. Results shown in Fig. 1 (a) suggest that the strong wall lithiumization promotes the occurrence of the LHCD effect at high density. The frequency spectrum collected by a RF probe located outside the machine consists a broadening at around the LH wave operating frequency, and a sideband shifted of an amount in the range of the ion-cyclotron frequency (IC-sideband). The observed trend of increase the IC sideband level with density (see Fig. 1(b)) is consistent with the sharp decay of HXR, supporting that the PI plays a key role in affecting LHCD. Lower electron density in the edge region in the case of strong lithiation (see Fig. 2) reduce PI [6] as well CA [4], thus providing condition favorable for the occurrence of the LHCD effect into the plasma core.

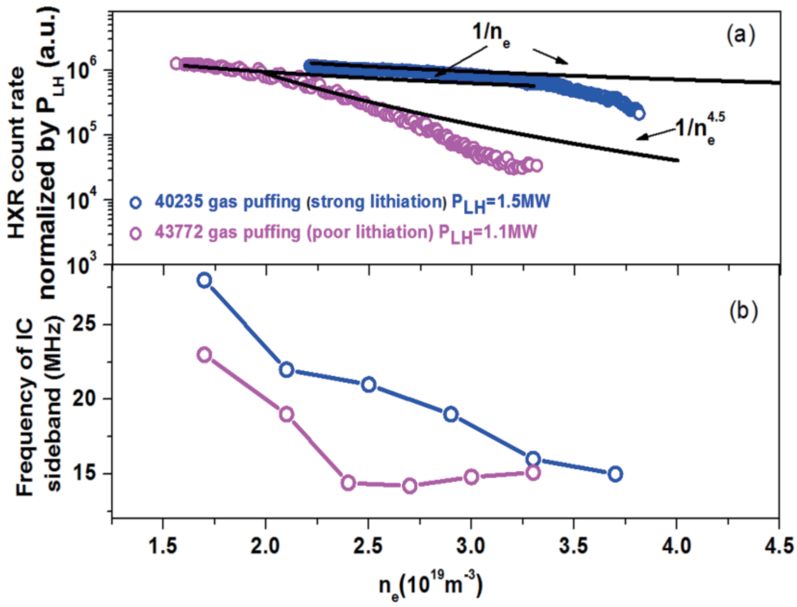

Fig. 1 (a) Relationship between HXR counts and density (b) Frequency of IC sidebands

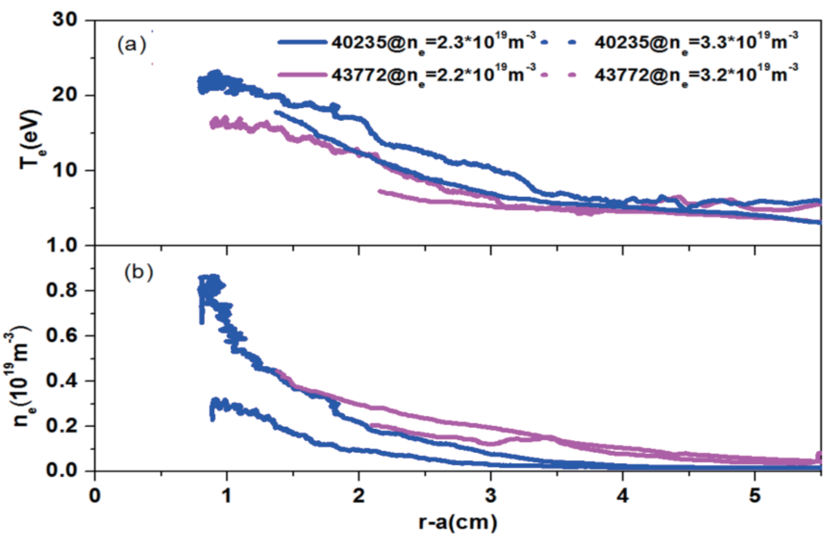

Fig. 2 Edge temperature (a) and (b) density profile measured by Langmuir probe

2.2Effect of LH frequency (4.6GHz *vs* 2.45GHz) [10]

In order to study the effect of frequency on LHCD characteristics, two different frequency waves (2.45GHz and 4.6GHz) with the same power (P_{LH} = 1.05MW) were injected successively in one discharge with almost constant density ($n_e = 2.0 \times 10^{19}m^{-3}$) and the typical waveform are shown in Fig.3. It is seen that the residual voltages (V_{loop}) are 0.27V and 0.18V respectively for current drive with 2.45GHz and 4.6GHz, indicating better CD efficiency for 4.6GHz waves. Also, the internal inductance is higher with the 4.6GHz LH wave injection, indicating the difference in the current profile. Though power spectrum is an important parameter affecting wave propagation and power deposition, simulations suggest that the discrepancy in the initial spectrum could not dominate the difference in current drive. A comparison of frequency spectra between two waves is illustrated in Fig. 4, from which it is seen that larger spectral broadening occurs for 2.45GHz case, indicating stronger PI behaviour. This result would explain the better CD effect with 4.6GHz LH wave in terms of reduced parasitic PI effect, as previously reported [6,11].

The related results indicate that the 4.6 GHz frequency is more useful for producing stronger LHCD on EAST, and that the 2.45 GHz operation would require an optimization in terms of PI effect mitigation, hence, optimizing current profile.

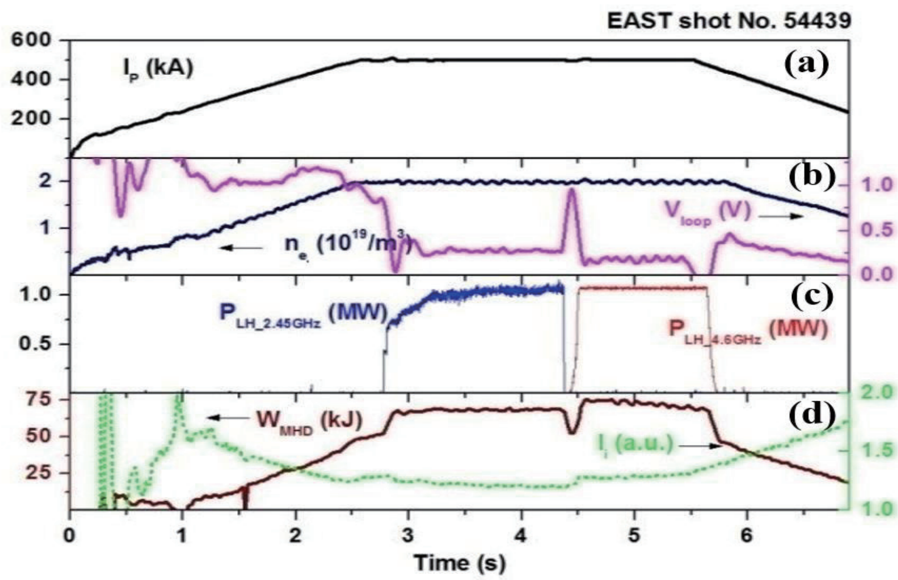

Fig. 3 Effect of LH frequency on LHCD

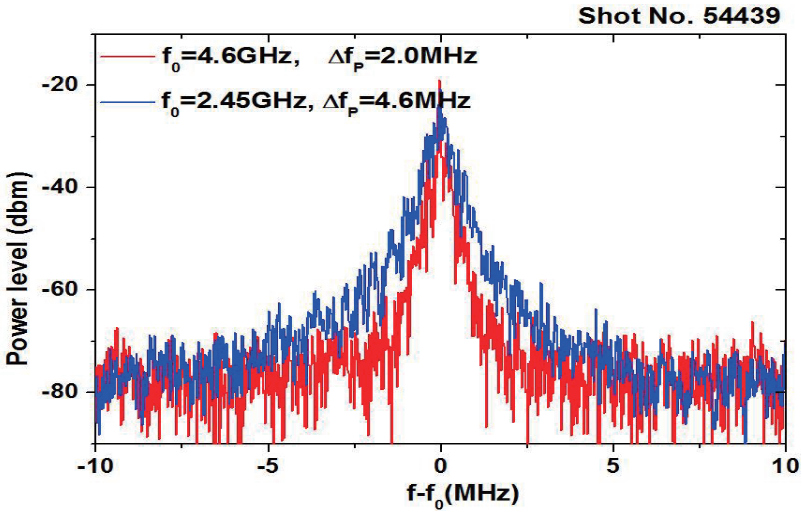

Fig. 4 Frequency Spectrum by a RF

3. Effect of LH spectrum on LHCD (4.6GHz and 2.45GHz) [12]

To explore long pulse and high performance with LHCD, the effect of LH spectrum with 4.6GHz system on LHCD characteristics was investigated [12] in EAST. The experiments were carried out with different toroidal phase differences (Δφ=0° , 90° , 180° , -90°) between the main waveguides. Experimental results are shown in Fig.5. It is seen that the smallest consumptions of magnetic flux in Fig. 5(d) occurs with Δφ=900, suggesting the highest CD efficiency. The internal inductance (l_i), shown in Fig. 5 (e), is the largest with Δφ=90° , whereas it is the lowest with Δφ=-90° , implying the most peaked current density profile with Δφ=90° . Possible reason for the discrepancy in the CD characteristic between the four cases could be that the spectrum in the main lobe with Δφ=90° has a single main peak, whereas the others are compound, especially in the case of Δφ=-90° . Such preliminary results indicate the possibility of profile control by changing the wave spectrum.

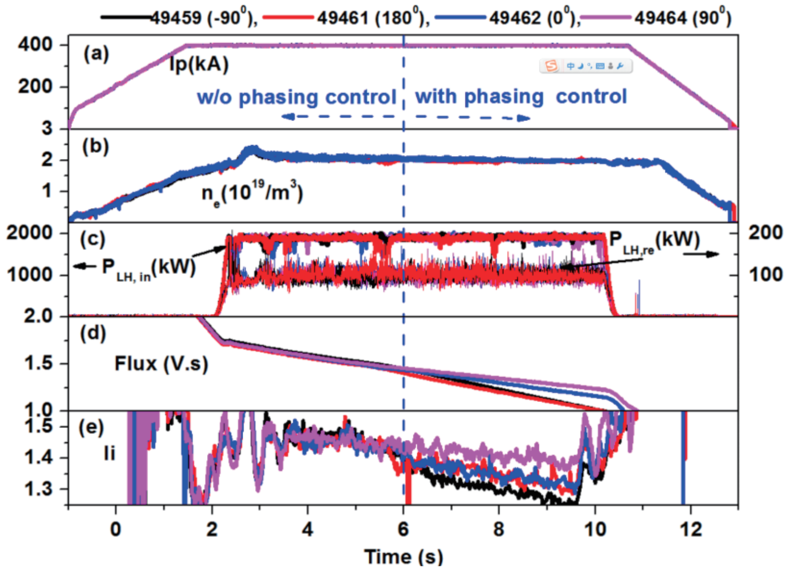

Fig. 5 Effect of spectrum on CD efficiency and current profile

4. Effect of density on LHCD (4.6GHz) [13]

On EAST, effect of density on current profile was investigated. The electron density was systematically varied in order to modify the deposition profile of the external LHCD, while keeping the plasma in fully-noninductive conditions to avoid Ohmic current that would tend to peak the current profile. The LHCD profile is expected to become more off-axis with higher density and the total current profile should become broader at higher density. The EAST experiments achieved a series of L-mode edge, noninductive discharges with I_p = 400 kA and line averaged density in the range 1.8–3 × 10^{19} m^{-3}. As expected, the current profile broadened with increasing density, as shown in figure 6 by the lower value of the internal inductance, l_i. Results of the reconstructions are shown in figure 7, confirming that broader current profiles are obtained at higher density.

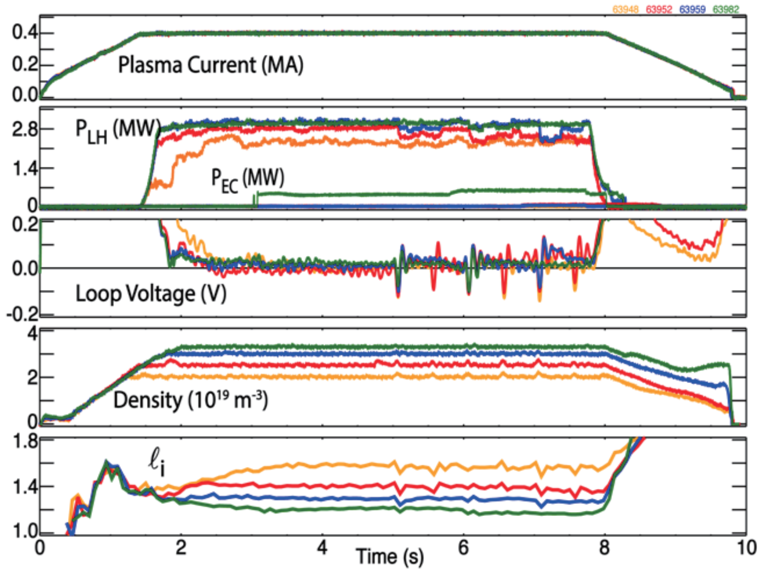

Fig. 6 Effect of density on LHCD

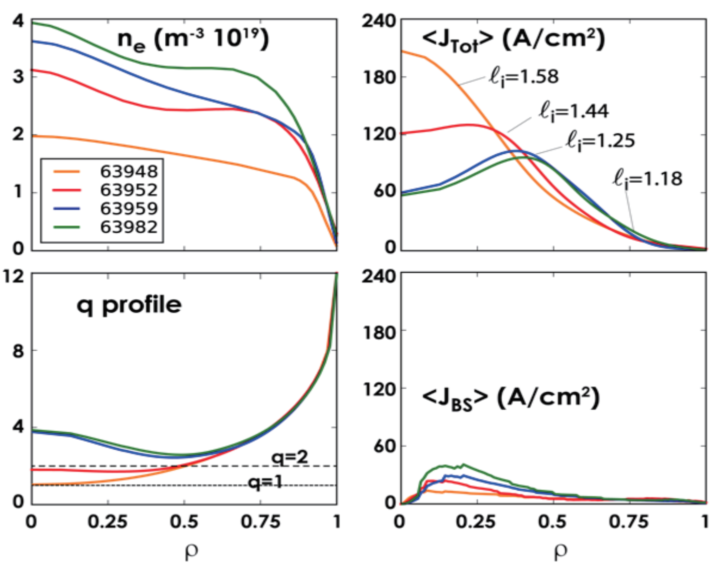

Fig. 7 Radial profiles for 4 didischarges

5. Conclusion

The effect of LHCD on current profile was summarized, including edge parameters, LH frequency, LH spectrum and plasma density. The role of parasitic effects of edge plasma on LHCD is studied and it can be mitigated by increasing source frequency or lowering recycling. Lower recycling and higher LH frequency are preferred for LHCD at higher density. Effect of LH spectrum and plasma density on LHCD suggests that the optimization is possible methods to control current profile.

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