Linkage between LHCD and density fluctuation in edge region on EAST

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Abstract Recently, experimental effect of density fluctuation in edge region on LHCD (lower hybrid current drive), another candidate related to parasitic effect, has been observed for the first time in EAST. Results show that density fluctuation is affected by RMP (resonant magnetic perturbation) application at density of $3.5x10^{19}m^{-3}$. The current drive capability indicated by the loop voltage improves with the decreasing density fluctuation. Meanwhile, the internal inductance enhances, indicating a peaked plasma current profile. Such degradation of LHCD at higher density fluctuation is mainly ascribed to the effect of density fluctuation in edge region on launching wave, which is firstly evidenced by the frequency spectrum measurement, leading to more power deposited in the edge region. Results are encouraging considering that the LHCD tool is essential for control of current profile in reactor grade plasmas.

1. Introduction In order for the tokamak to be a commercially viable energy source, it will be necessary to operate these devices in 'advanced' modes characterized by high energy confinement and high fractions of the non-inductive bootstrap current [1]. Lower hybrid current drive (LHCD) [2-4] in principle satisfy this current profile control need, but the coupled radiofrequency (RF) power faces the challenge of effectively penetrating into the main plasma at the relatively high edge density, possibly due to parametric instability (PI) [5, 6], collisional absorption (CA) [7] and scattering by density fluctuation (SDF) [8-10] in the edge region. Studies in EAST show that lower recycling and higher source frequency are

preferred to improve LHCD capability at high density due to the mitigation of parasitic effects of edge plasma, mainly ascribed to PI and CA in edge region [11,12]. A link between the degradation of current drive (CD) efficiency and the spectral broadening is found, showing that the spectral broadening has a negative and significant effect on CD efficiency. Here, we would like to describe experiments and analysis that demonstrate the effect of density fluctuation in edge region on LHCD in EAST.

2. Experiment and results The typical discharge (#78000) waveforms with a coupled power ($P_{\mathrm{LH\text{-}2.45}}$~1MW, $P_{\mathrm{LH\text{-}4.6}}$~2MW) and an almost constant density (n_e=3.5 × 10^{19}m^{-3}) in a USN configuration are shown in Fig. 1. The peak value of the antenna power spectrum has a refractive index along the direction of the toroidal magnetic field of $N_{//0} \approx 2$. Note that RMP (resonant magnetic perturbation) was applied during 1.5s~5s, after which the density and its fluctuation decrease sharply, suggesting the effect of RMP on edge density. It is seen that the residual voltage (V_{loop}) (Fig.1 (b)) drops off suddenly when the RMP is switched off. At the same time, the counts of hard-X ray increases (see Fig. 1(c)), suggesting that more current is driven. The internal inductance decreases, implying a broader current profile due to more driven current outside the core region. This is possibly because the wave mainly deposits outside half minor radius due to the poor accessibility condition [13]. Furthermore, as shown in Fig. 2, the change in loop voltage is linear with the variation of density fluctuation. Results suggest that the current drive efficiency is improved after the termination of RMP, possibly due to the change of edge parameters affected by RMP.

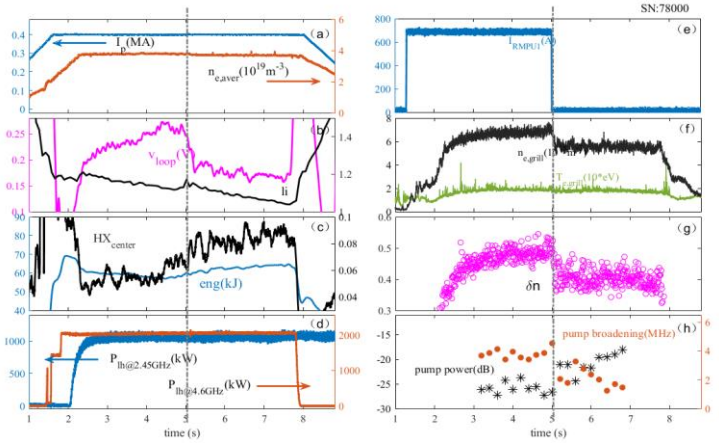

Fig. 1 Typical waveforms of effect of density fluctuation on LHCD

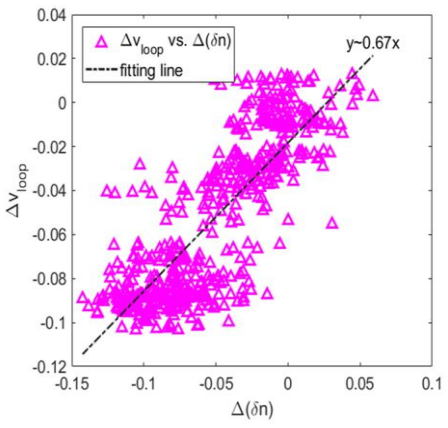

Fig. 2 change in loop voltage vs variation of density fluctuation

3. Analysis Effects of PI and SDF in modifying the initial wave spectrum may play an important role in determining properties of wave propagation and damping in the plasma, hence possibly affecting power deposition and current drive. Such nonlinear effect can be indicated by the pump wave and its broadening measured with a loop antenna for the 2.45GHz wave outside the machine (see Fig. 3). The appearance of side band suggests that PI occurs through ion cyclotron channel. Furthermore, as seen in Fig. 1 (h), detailed pump wave and its broadening, which may result from PI through ion sound channel and SDF, are expanded from the measurement of loop antenna. It shows that the power of pump wave increases and the broadening decreases after the termination of RMP application, consistent with the change in loop voltage. Since PI and SDF are mainly related to the parameters in SOL, here we would like to focus on the edge parameters in detail, which are measured by a Langmiur probe mounted near the LH antenna. Seen from Fig. 1(f) (g), in addition to the density fluctuation, the electron density in edge region also decreases after the RMP switched off, meanwhile, the electron temperature in edge region nearly doesn't change so much at the time. Such change in density and temperature may lead to different PI behavior.

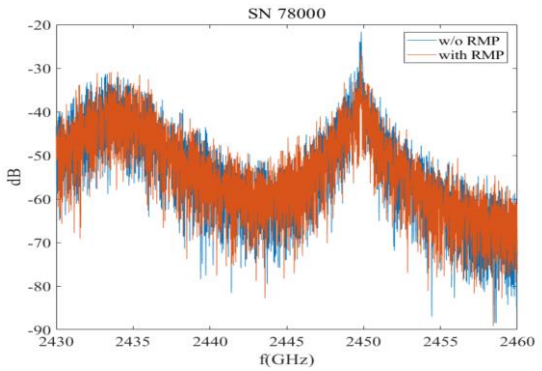

Fig. 3 PI spectrum measured by loop antenna

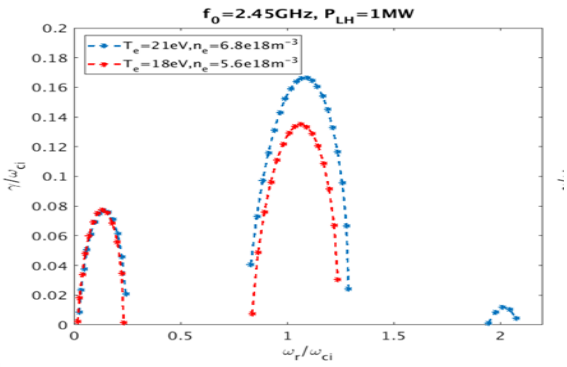

Fig. 4 PI modeling (2.45GHz)

To investigate the effect of edge parameter on LHCD, using the measured density and temperature (T_e=21eV, n_e=6.8×$10^{18}$$m^{-3}$, and T_e=18eV, n_e=5.6×$10^{18}$$m^{-3}$) during the period with and without RPM, PI (including ion cyclotron mode and ion sound mode) [14] is simply estimated and shown in Fig. 4. Simulations show the presence of the growth rate of ion cyclotron mode, consistent with the observed IC sideband in Fig. 3. Meanwhile, the difference in the growth rate with and without RMP is not large and the experimental parameters

of density and temperature may be within the measurement error bars. So, it may not account for the difference in LHCD capability with and without RMP. In addition, growth rates of the ion-sound mode are almost the same for the two cases, implying that there is no difference in the contribution of spectrum broadening. Since the broadening due to ion sound mode is excluded, it is inferred that the change of measured spectrum broadening mainly comes from density fluctuation. Therefore, the linkage between LHCD and density fluctuation in edge region is documented.

4. Conclusion By means of application RMP application, the linkage between LHCD and density fluctuation in edge region on LHCD, another candidate related to parasitic effect, has been demonstrated for the first time in EAST. Results show that density and its fluctuation are affected by RMP application at density of $3.5x10^{19}m^{-3}$. The current drive capability indicated by the loop voltage improves with the decreasing density and its fluctuation. Such degradation of LHCD at higher density fluctuation is mainly ascribed to the effect of density fluctuation in edge region on launching wave, which is firstly evidenced by the frequency spectrum measurement. Since LHCD performance is improved with a reduction in edge density fluctuations, control in the edge density fluctuation is important for a successful current drive in a reactor. Further studies will be continued.

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References: [1] S. C. Jardin *et al*, Fusion Engineering and Design 38, 27–57 (1997). [2] N.J. Fisch. Phys. Rev. Lett. 41 873 (1978). [3] S. Bernabei *et al*, Phys. Rev. Lett. 49 1255 (1982). [4] N. J. Fisch, Rev. Mod. Phys. 59 175 (1987). [5] C. S. Liu and V. K. TRIPATHI, Phys. Rep.130143 (1986). [6] R. Cesario *et al*, Phys. Rev. Letters, 92 175002 (2004). [7] P. T. Bonoli et al, Phys. Fluids 29 2937 (1986). [8] Y. Peysson *et al*., Plasma Phys. Contr. Fusion 53 124028 (2011). [9] N. Bertelli et al, Plasma Phys. Control. Fusion 55 074003 (2013). [10] G Vahala et al Phys. Fluids B: Plasma Physics **4**(1992) 4033. [11] B J Ding et al., Nucl. Fusion **53** (2013) 113027. [12] B J Ding et al., Nucl. Fusion **58** (2018) 126015. [13] Y. Takase *et al*, Phys. Fluids 28 983 (1985). [14] M Porkolab, Physics of Fluids **20** (1977) 2058.