5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

Low-frequency MHD Modes Driven by Energetic Electrons in HL-2A LHCD Plasmas

L.M. Yu, W. Chen, Z.B. Shi, T.B. Wang, X.T. Ding, X.Q. Ji, P.W. Shi, R.R. Ma,X.Y. Bai, J.X. Li, B.S. Yuan,Y.G. Li, YI Liu, W.L. Zhong, M. Xu and X.R. Duan
Southwestern Institute of Physics, Chengdu, China, e-mail: yulm@swip.ac.cn

The energetic electrons (EEs) can be generated directly by radio frequency heating (electron cyclotron resonant heating/current drive (ECRH/ECCD), low hybrid current drive (LHCD)) and toroidal Ohmic electric field. Besides, energetic ions (EIs), produced by neutral beam injection (NBI) and ion cyclotron resonant heating (ICRH), and 3.5 MeV alpha (α) particles generated by D-T reaction in burning plasma will heat the background electrons firstly, when the energy of EIs and α is higher than critical energy [1]. Abundant EEs induced magnetohydrodynamic (MHD) instabilities and even their nonlinear interactions have been identified and studied [2-12]. The small resonant particle orbit width of EEs can be utilized to simulate and analyse the analogous effect of α characterized by small dimensionless orbits similar to EEs in tokamak plasmas [12, 13]. The LHCD system is designed and planned for off-axis current drive and assisted ramp-up in the second phase of International Thermonuclear Experimental Reactor (ITER) operation [14]. The MHD instabilities maybe excited by the EEs during high-power LHCD.

Two kinds of basic EE induced low-frequency MHD instabilities [7], e.g., core localized electron fishbone (e-FB) mode and edge localized electron beta-induced Alfvén eigenmode (e-BAE), are found in co- and counter-current drive LHCD plasmas on HL-2A, respectively. The e-BAEs in LHCD plasmas are found for the first time.

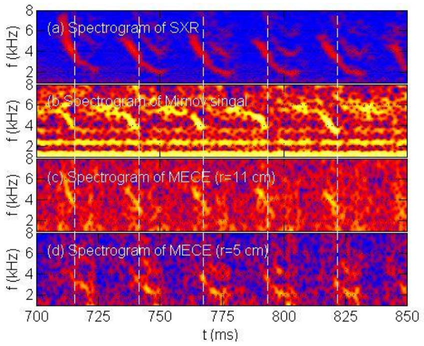

Fig.1 E-FB modes observed from spectrograms of (a) SXR signal with d = 7.3 cm, (b) Mirnov signal, (c) and (d) microwave interferometer signals with r = 11 and 5 cm, respectively.

Two branches e-FB modes are observed in the core of plasma, and they can transit from the high-frequency (8-4 kHz) one to the low-frequency (4-2 kHz) one continuously. The m/n=1/1 and 2/2 mode structures and r~11 and 5 cm positions are identified by soft X-ray arrays and their tomography, where m and n are the poloidal and toroidal mode numbers, as shown in Fig.1. Four branches of e-FB modes with various frequencies of 2-5, 5-7, 10-12 and 13-15 kHz are observed on the spectrogram of the core soft X-ray (SXR) signals (inside q=1 surface). The frequencies jump phenomena of four e-FB modes and even their co-existance are also found.

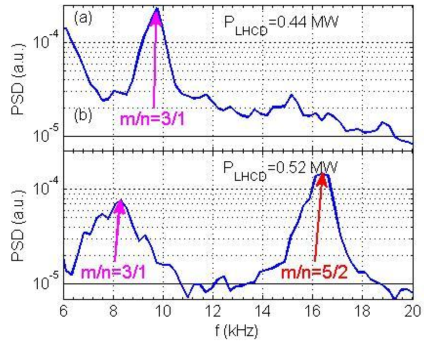

Fig.2 Averaged power spectral density of poloidal Mirnov signals for shot (a) P_{LHCD}=0.44 and (b) 0.52 MW.

The m/n=3/1 and 5/2 e-BAEs are found in the edge of plasma. The single 9-11 kHz m/n=3/1 mode is found when LHCD power (P_{LHCD}) is 0.44 MW. The strong 15-17 kHz m/n=5/2 mode coexists with the weak 7-9 kHz 3/1 mode when P_{LHCD}=0.52 MW, as shown in Fig.2. Although, the current drive direction of LHCD is opposite with plasma current, the two e-BAEs also propagate in electron diamagnetic drift direction poloidally. The frequencies of the two modes are closes to continue accumulation point frequency frequency of BAE. With the increase of P_{LHCD}, the value of safety factor (q) near r~ 29 cm decreases from 3.0 to 2.5 in which the e-BAEs located. It's indicated that the variation of mode numbers are caused by the changed q values near mode position.

The investigation on MHD instabilities in different current drive direction LHCD plasmas can be used to predict and solve the potential problems in the LHCD plasmas.

References

[1] J. Jacquinot et al. Nucl. Fusion 39, 2471 (1999).
[2] X.T. Ding et al. Nucl. Fusion 53, 043015 (2013).
[3] X.T. Ding et al. Plasma Sci. Technol. 20, 094008 (2018).
[4] L.M. Yu et al. Nucl. Fusion 53, 053002 (2013).
[5] L.M. Yu et al. Nucl. Fusion 57, 036023 (2017).
[6] L.M. Yu et al. Phys. Plasma 25, 012112 (2018).
[7] L.M. Yu et al. Nucl. Fusion 61, 026019 (2021)
[8] W. Chen et al. Nucl. Fusion 49, 075002 (2009).
[9] W. Chen et al. Phys. Rev. Lett. 105, 185004 (2010).
[10] W. Chen et al. Nucl. Fusion 51, 063010 (2011).
[11] W. Chen et al. Nucl. Fusion 53, 113010 (2013).
[12] G. Vlad et al. New J.Phys. 18, 105004 (2016).
[13] F. Zonca et al. Nucl. Fusion 47, 1588 (2007).
[14] J. Jacquinot et al. Fusion Engineering and Design 84, 125 (2009).