Operation of HL-2A Tokamak

X. R. Duan, Y. Huang, D. Q. Liu, W. M. Xuan, L. Y. Chen, J. Rao, X. M. Song, Z. Cao, B. Li, J. Y. Cao, G. J. Lei, X. D. Li, Yi Liu, Q. W. Yang, L. Y. Yao, X. T. Ding, J. Q. Dong, L. W. Yan, C. H. Pan, and Yong Liu

Abstract—The operation conditions have been improved via developing new technologies and improving the hardware on HL-2A tokamak in recent years. The ECRH system has been upgraded to 3 MW/68 GHz, the supersonic molecular beam injection (SMBI) fuelling technique has been developed further, and clusters can be formed in the SMB by cooling the gas to around liquid nitrogen temperature, so that deeper penetration can be achieved. Moreover, there are about 30 kinds of diagnostics developed on HL-2A to measure the plasma parameters. These diagnostic systems include magnetics, microwave reflectometry, charge exchange recombination spectroscopy, Thomson scattering, FIR interferometer. Some of them were specially designed for the physics experiments. For example, a novel design of Langmuir probes was developed to study the 3-D structure of zonal flows. With these hardware development and improvement, new experimental results have been achieved in the fields of turbulence, transport, MHD instabilities, and energetic particle dynamics. In particular, the edge localized mode (ELM)/H-mode has been achieved by combining the auxiliary heating of NBI and ECRH, SMBI is beneficial for the L-H transition and the H-mode operation on HL-2A, and suitable for studying particle transport and controlling the ELMs during H-mode discharges due to its deep and local injection features and good controllability. In addition, the 3-D spectral structures of the low-frequency zonal flow and quasi-mode, which were predicted by theory and simulation, have been observed simultaneously. The beta-induced Alfvén eigenmodes (BAEs), excited by large magnetic islands (m-BAE) and by energetic electrons (e-BAE), are investigated, these phenomena are under further study.

Index Terms—electron cyclotron resonance heating (ECRH), ELM mitigation, HL-2A tokamak, H-mode, lower hybrid current drive (LHCD), neutral beam injector (NBI), pellet injection (PI), supersonic molecular beam injection (SMBI), wall conditioning.

I. INTRODUCTION

HL-2A tokamak [1], [2] is characterized by upper and lower closed divertor chambers, with main parameters of the major radius \( R = 1.65 \) m, the minor radius \( a = 0.4 \) m, the area of the main plasma-facing wall \( S = 31 \) m\(^2\), and the flux swing of \( 5.0 \) Vs. It consists of vacuum vessel and magnetic coils, pumping and wall conditioning system, auxiliary heating and fuelling system, central control and data acquisition system. The divertor pumping system is composed of fourteen titanium getter pumps installed in the divertor chambers. The power supply system [3]–[5] is equipped with two identical 90 MVA flywheel motor generator (MG) sets and one 125 MVA MG set. The former provides power for 16 D-shaped toroidal field (TF) coils to obtain the toroidal magnetic field \( B_t = 2.8 \) T with a flat-top of \( 3 \) s, \( 5 \) s, central electron \( T_e = 5 \) keV and ion temperatures \( T_i = 2.8 \) keV.

The mission of HL-2A project [14]–[16] is focused on those key scientific and engineering issues related with ITER, such as high confinement mode (H-mode), L-H transition, edge localized mode (ELM) dynamics and ELM mitigation, zonal flow and turbulence characteristics, particle and thermal transport, energetic particle physics and MHD control, plasma fuelling and heating methods, disruption mitigation. With the progress of hardware improvements in recent years, the first ELMy H-mode discharges [17] in China were achieved on HL-2A in 2009 by using the NBI heating and the 2nd harmonic X-mode ECRH. The remainder of this paper is arranged as follows. Procedures of wall conditioning for better controllable plasma discharges are demonstrated in Section II. Technologies and improvements of auxiliary heating and fuelling systems are...