P29-DPP2017

1st Asia-Pacific Conference on Plasma Physics, 18-22, 09.2017, Chengdu, China

Fusion Research at SWIP in Support to ITER and CFETR

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The fusion research activities at Southwestern Institute of Physics (SWIP) include the HL-2A & HL-2M tokamak program, ITER procurement packages, other key fusion technologies, fusion reactor design and materials. As an important part of the fusion research programme of China, the key mission of the HL-2A/HL-2M tokamak program is to explore physics issues involved in advanced tokamaks and to address the physic and technologic issues in support to ITER and Chinese Fusion Engineering Test Reactor (CFETR), especially since the realization of high confinement mode discharge in 2009 [1]. Most of the important issues of fusion physics, such as turbulence and transport, energy confinement improvement, pedestal physics, MHD instabilities and energetic particle physics, divertor and scrape-off layer physics, heating and current drive have been investigated through the progressive improvement of the many subsystems of HL-2A. This contribution highlights some of the prominent example of the research achievements in HL-2A during recent years.

I. L-H transition physics. In tokamaks, zonal flow plays a crucial role in the formation of transport barrier and the achievement of improved confinement regimes by suppressing the turbulence and reducing the transport. In HL-2A, pioneering work contributed to this topic has been intensively performed, such as the measurement of 3-D structure of geodesic acoustic mode (GAM) zonal flow [2], the coexistence of zonal flow (LFZF) and GAM [3], the importance of nonlinear energy transfer between turbulence and zonal flows in L-H transition [4], the observation of two types of limit-cycle-oscillations prior to the H-mode revealing the critical role of pressure gradient driven shear flow in H-mode access [5], and the synchronization of GAM and magnetic fluctuations [6].

II. Core plasma physics. The performance of core plasma determines the global energy confinement, and hence the fusion reaction efficiency of burning plasma. With regard to particle transport in the core plasma region, a spontaneous particle transport barrier has been observed in Ohmic discharges [7]. The formation of the barrier has been related to the turbulence transition between the trapped electron mode and the ion temperature gradient driven mode, which results in the convective velocity reversal of particle transport [8]. Non-local heat transport has been extensively investigated in HL-2A, e.g. the study on the interplay between neoclassical tearing modes and nonlocal transport has important implications for the understanding of multi-scale transport dynamics [9].

III. Pedestal physics and ELM control. One of the major challenges for the magnetic fusion community is the heat exhaust from the core without damaging the plasma facing components. The formation of a steady-state edge localized radiation layer with impurity seeding is one of the envisaged solutions. In HL-2A tokamak, it has been shown that such impurity radiation layer exists, and is self-regulated by electromagnetic turbulence with double impurity critical gradients [10]. At the aspect of actively protecting plasma facing components, supersonic molecular beam injection, a fuelling tool that was proposed and demonstrated for edge localized mode (ELM) mitigation in HL-2A, and has been used to successfully mitigate giant ELMs in the large tokamaks, such as EAST and KSTAR [11].

IV. MHD and energetic particle physics. Macro-scale plasma instability, such as MHD and energetic particle driven modes, will significantly degrade the plasma confinement performance or cause plasma disruption which may damage the fusion reactor. To identify the instabilities and then control them is highly desirable for fusion research in tokamaks. In HL-2A, a lots of this instabilities have been observed, for instance, the beta induced Alfven eigenmode (BAE), excited by energetic electrons, has been identified for the first time in HL-2A both in the Ohmic and electron cyclotron resonance heating plasmas [12].

V. HL-2M program. HL-2M is under construction with a capability to operate up to 3MA, 3T and 25 MW of heating and current drive power. The research program of HL-2M will support future machines (ITER, CFETR) addressing divertor Physics in exploring various advanced divertor configurations (snowflake, tripod), burning plasma physics issues, and advanced tokamak scenario as well. Plasma scenario development has been carried out [13]. Advanced Tokamak regimes can be achieved by combining NBI with controlling the off-axis ECCD, allowing to access high beta-N regimes with beta-N ranging from 2.5-4.5 (Ip=0.8MA-1.5MA). Complementarily to bootstrap current and ECCD, far off-axis LHCD can help accessing and extending the duration of Steady-State fully non-inductive plasmas.

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