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Progress of HL-2A Experiment and HL-2M Program

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As an important part of the fusion research program in China, the key missions of the HL-2A and HL-2M tokamak programs are to explore physics and technology issues and provide research basis in support of ITER and fusion reactors. This overview reports the latest progresses in HL-2A programs, including high performance scenarios for the study of advanced plasma physics, ELM control physics and technology development, abnormal event mitigation and prediction, and nonlinear physics [1-6]. Finally, the upcoming tokamak HL-2M [7,8] is presented.

By using the upgraded NBI and LHCD systems, a high-performance operation regime ($\beta_N > 3.0$ and $H_{98y2} \sim 1.3$) with both edge and internal transport barriers has been obtained. This scenario has been successfully modeled using integrated simulation codes (OMFIT, METIS). Moreover, these experiments provide an important platform for studying MHD physics, such as neoclassical tearing mode, Alfvén modes and so on in high performance plasmas. The H-mode performance has been further improved by impurity seeding (Ne or Ar) via supersonic molecular beam injection. In these experiments, ion temperature in both edge and core plasmas are increased by a factor of 20%-40% after the impurity seeding, and the ion and electron heat flux exhibits distinct responses to the impurity seeding. The result suggests that the seeded impurity could change the core thermal transport, resulting in a higher ion temperature and an enhanced energy confinement.

ELM physics understanding and its mitigation, as well as the development of control technique have been investigated intensively in HL-2A. Recently, type-I ELM suppression by applying n=1 resonant magnetic perturbation (RMP) in HL-2A is explained by the enhancement of turbulence during RMP. These results demonstrate that stochastic boundaries by simple n=1 coil are compatible with H-mode and could be attractive for ELM control in next-step fusion tokamak. For ELM control with impurity seeding, it has been found that the ELM mitigation and ELM suppression could be realized by seeding different quantity of impurities. Dual effects of the laser blow-off (LBO) impurity seeding have been found on the pedestal turbulence, which are due to different mechanisms. For RF wave, the impact of off-axis ECRH on ELMs and pedestal behaviors have been studied in HL-2A. The result shows that the off-axis power deposition and accompanied reduction of co-current toroidal rotation increases ELM frequency. Further improvement of the reliability and robustness of the ELM control approach is the high priority of the research.

Issues concerning abnormal event such as disruption needs to be resolved in future fusion devices. The effects of LHCD and LBO on runaway electrons (RE) dynamics during disruptions have been investigated. RE generation during disruptions has been avoided for the first time by the LBO-seeded impurity. Moreover, the enhancement of RE generation during disruption with LHCD has been found. To predict disruption, a predictor based on deep learning method has been developed in HL-2A. It reaches a true positive rate of 92% and a true negative rate of 97% with 30ms before the disruption. This model interpretation method can be used to automatically give the disruption causes, which will be helpful for the active avoidance of disruption.

Regarding the progress on nonlinear physics, a new experiment evidence about the EPM avalanche is demonstrated in the HL-2A tokamak. The change rate of the frequency is proportional to mode amplitude, which agrees with the RRM model. A profound influence of the island size on the nonlinear effect of turbulence on transport has been studied. The results indicate that there are strong nonlinear interactions between the tearing mode (TM) island and turbulence. Aiming to approach a whole-device integrated simulation, a massive parallel initial value code—extended fluid code (ExFC), has been newly developed using 3D finite difference scheme while the code is well-benchmarked versus gyro-kinetic (GK) simulations. The cross-phase dynamics in Reynolds stress and particle flux have been studied.

To support reactor-grade machines, HL-2M (R=1.78m, a=0.65m) is under construction with a capability to operate up to 3 MA, 3 T and 30 MW of H&CD power. Each TF coil of HL-2M can be assembled and disassembled by demountable joints. It allows the poloidal coils to be closer to the plasma, resulting in a high flexibility for magnetic configuration. Another important feature of HL-2M is its capabilities to operate under advanced divertor configurations like snow flake divertor and tripod divertor. Key missions of HL-2M are to address divertor physics and heat exhaust issues in various advanced divertor configurations and to explore burning plasma related physics, and advanced tokamak scenarios as well. Plasma scenario development has been carried out. It is expected that a combination of NBI and off-axis ECCD will allow accessing β_N ranging of 2.5-4.5 (Ip=0.8MA-1.5MA) [9]. In addition, far off-axis LHCD can help to access and extend the duration of steady-state fully non-inductive plasmas.

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