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High Confinement Mode in the KSTAR Device and Control of Accompanying Edge Localized Mode

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1. Introduction

ELMy high confinement mode (H-mode) discharges [1] have been achieved in the Korea Superconducting Tokamak Advanced Research (KSTAR) tokamak [2] with the combined auxiliary heating of neutral beam injection (NBI) and electron cyclotron resonance heating (ECRH) since the 3rd campaign in 2010. The minimum external heating power required was about 0.9 MW at a line-averaged density higher than 1.4×10^{19} m^{-3} and a toroidal field of 2 T. A clear increase of electron and ion temperatures in the pedestal was observed in the H-mode phase while the core ion temperature did not change notably. The toroidal rotation also increased over all radii in the H-mode phase. The measured ELM frequency was around 30~50 Hz and the drop of the total energy appeared to be less than 5 %. Between large ELM spikes, small/grassy ELMs were also identified when mixed heating of NBI and ECRH was applied. On the basis of the H-mode achievement in the 3rd campaign, the 4th campaign experiments were focused on the ELM control by various methods such as resonant magnetic perturbation (RMP), supersonic molecular beam injection (SMBI), vertical jogging of plasma column, and edge current drive. Abrupt burst of stored energy due to ELM is harmful to plasma facing component especially in reactor scale devices like international thermonuclear experimental reactor (ITER) [3]. The aforementioned ELM control experiments were supported by advanced diagnostics such as electron cyclotron emission imaging (ECEI) and X-ray imaging crystal spectroscopy (XICS). In the 3rd campaign, the ECEI observed the evolution of filamentary ELM structures in 2D and the XICS measured the plasma rotation profile enhanced by H-mode. Furthermore, the analyses based on advanced diagnostics are in progress for investigating the underlying physics of edge/pedestal characteristics when applying ELM control methods.

2. Typical H-mode discharges of the KSTAR device

As shown in Fig. 1, the stored energy significantly increases around 1.8 s (shot #4200) and 2.0 s (shot #5802). The stored energy might be increased by additional heating as well. However the increase of stored energy around the depicted times is originated from the improvement of confinement since the amount of auxiliary heating power is same. The achievement of H-mode was possible due to the reduction of wall recycling by diverted configuration of plasma and sufficient heating power above the threshold power required for the transition from low confinement mode (L-mode) to H-mode.

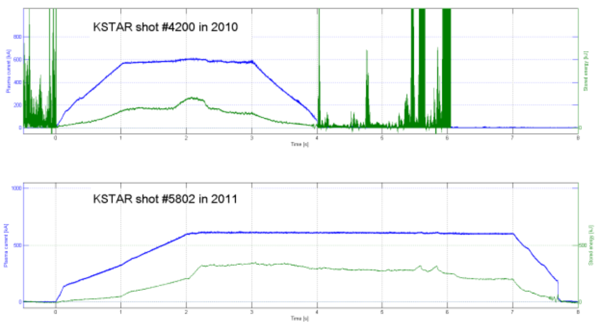

Fig. 1. Typical H-mode discharges. Blue and green lines depict plasma current and stored energy respectively.

3. ELM control

It is generally regarded that ELM instability is caused by steep pressure gradient and over-driven edge current density originated from improved confinement of energy and particle in H-mode. Thus the ELM control method could be classified two different ways. One is to prevent the build-up of unstable ELM condition by slightly degrading the confinement. The other is to make a stimulated ELM burst in order to reduce the bursting power per each ELM.

RMP and edge Ohkawa current drive are corresponding to the former way and the vertical jogging of plasma column and pellet pace-making are typically used for latter stimulating ELM burst.

3.1 Resonance Magnetic Perturbation

The segmented in-vessel control coil (IVCC) system of the KSTAR device is capable of applying n=1 or 2 RMP with various parity. The application of n=1 RMP showed an apparent ELM suppression and mitigation in various parity as depicted in Fig. 2.

3.2 Vertical Jogging of Plasma Column

Furthermore, the versatile IVCC can make a fast vertical jogging of plasma as well. By using the vertical jogging faster than natural (uncontrolled) ELM frequency, we could manage ELM bursting frequency up to 100 Hz which was originally 30~50 Hz. It is well known that the loss of stored energy is inversely proportional to ELM frequency.

3.3 Supersonic Molecular Beam Injection

The newly installed SMBI system was utilized for ELM control through the change of edge-pedestal characteristics. It was also shown remarkable ELM mitigation effect only by 2~3 pulses of SMBI per second.

3.4 Edge Ohkawa Current Drive

The 500 kW 110 GHz ECCD system was used for controlling the edge current based on the Ohkawa current drive. It affected on the change of ELM type although more analysis is needed for detailed understanding.

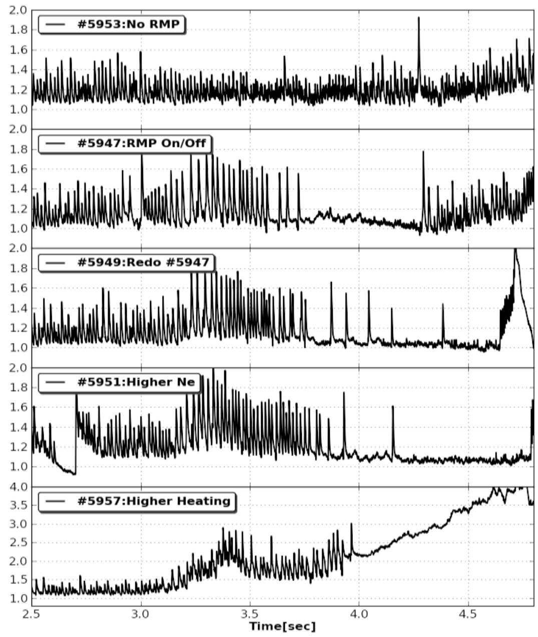

Fig. 2. ELM suppression and mitigation by applying RMP during H-mode phase. The spikes of H-alpha line corresponds to each ELM burst.

4. Conclusion

Since the first plasma of the KSTAR device in 2008, the performance of plasma has been gradually improved. By achieving H-mode discharge which is a main baseline scenario of the ITER device, the KSTAR device became prepared for contributing unsolved issues in thermonuclear fusion area.

The 4th campaign was focused on the control of ELM during H-mode since it is the most urgent issue in the ITER device. The various control methods were proven to be effective and the detailed analyses have been being conducted with diagnostic results.

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