The characteristics of the ion temperature and toroidal rotation velocity in the KSTAR plasma

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1. Introduction

Charge exchange spectroscopy (CES) is one of the important diagnostics on the Korea Superconducting Tokamak Advanced Research (KSTAR) to get ion temperature and toroidal rotation velocity [1-2]. We describe the current status and the improvements made over the last two years. The current system upgraded from a Czerny-Turner spectrometer consists of two spectroscopic systems looking at the KSTAR neutral beam which is modulated 5 Hz for special period[3-4]. One system has a DS spectrometer (f/2.8) lent from NIFS[5] with pitch-controlled double slit fiber bundle with back- illuminated CCD and the other system has K-spectrometer (F/2.0) made by NFRI with intensified CCD. The K-spectrometer has a grating number of 2400 g/mm, focal length of 200 mm. The upgrade of two high throughput spectrometers enables to improve the time resolution from 200 msec to around 10 msec. This article focuses on improved edge spatial interval from increasing of plasma viewing channels to 5 mm and enhanced time resolution from a high throughput spectrometer with back-illuminated CCD. The upgrade has allowed to measure pedestal ion temperature and toroidal rotation velocity profiles in KSTAR H-mode[6].

2. Ion temperature and rotation velocity in L- and H-mode plasma

The measurements of the ion temperature and toroidal rotation velocity profiles with the high spatial resolution have been conducted for the L- (black) and H-mode(red) plasma discharges in KSTAR as shown in Fig. 1. Figure1 shows the measured profiles of the ion temperature and the toroidal rotation velocity for shot number 5681 at the time of 2.015 and 2.435 sec in L- and H-mode. The plasma current is 630 kA, the line integrated density is 5.0×10^{19} m^{-2}. The NBI heating power and energy are 1.44 MW and 95 keV, respectively. The NBI modulation is from 2.2 sec to 3.2 sec with 5Hz frequency and duty 95 % such as the 190 msec on and 10 msec off.

Ion temperature gradient increased near pedestal in H-mode while it is monotonous near edge region in L-mode. Shear increased near pedestal in H-mode while it decreased near edge in L-mode. The pedestal structures both in the ion temperature and rotation speed were observed and the major radios of the last closed flux surface is around 2.25m in H-mode while the last closed flux surface is 2.3 m in L-mode.

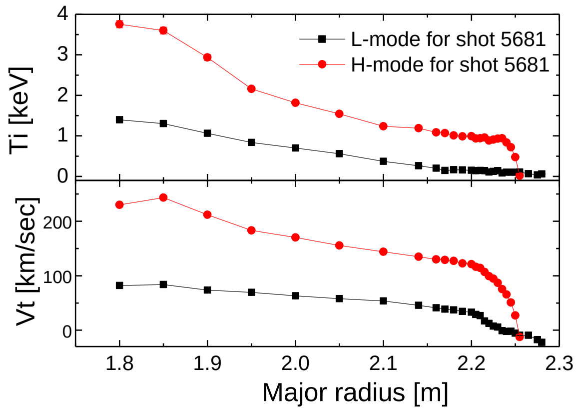

Fig.1. Typical L- mode and H-mode discharges. Black and red lines depict L-mode and H-mode respectively in the ion temperature and toroidal rotation velocity profiles of carbon VI line.

The differences in the edge regions between the L- and H-mode plasmas have been found very clearly due to the high spatial resolution measurement. As shown in Fig. 1, the ion temperature increases linearly in the edge region of the L-mode plasma. However, the ion temperature profile of the H-mode plasma shows that there is an abrupt increase – large radial gradient of the temperature in the edge region, which is representing the edge transport barrier (ETB). It seems that the large core temperature of the H-mode plasma relative to that of the L-mode plasma can be achieved by the formation of the ETB.

It is found that there is also a very sharp radial gradient of the toroidal rotation velocity in the edge region of the H-mode plasma. It also seems that the toroidal rotation velocity increases in the whole region of the plasma in the H-mode state compared to that of the L-mode state.

However, it is uncertain whether this increase of the toroidal rotation velocity is due to the large radial gradient of the velocity even though it seems that there is also a momentum transport barrier in the edge region like an ETB. Since the carbon velocity is expected to be much different from the main ion velocity in the edge region, the main ion velocity profile is necessary for the correct momentum transport analysis. The detailed transport analysis remains for the future since the estimation of the main ion velocity and the measurement of the radial electric field have not been available yet.

3. Characteristics of rotation velocity

3.1 The effect of ECH on rotation velocity

The central ECH causes significant drop in the central rotation. Both X-ray imaging crystal spectroscopy (XICS) and CES observed the core rotation reduction. CES data show that core rotation speed decreased about 80 km/sec but there is no change in pedestal rotation speed by ECH on-axis heating as shown in Fig. 2. The central and off-axis ECH show different effects on the central rotation in XICS data and CES will measure the effect on off-axis ECH heating. One big advantage of CES is detailed profile reaching up to the pedestal.

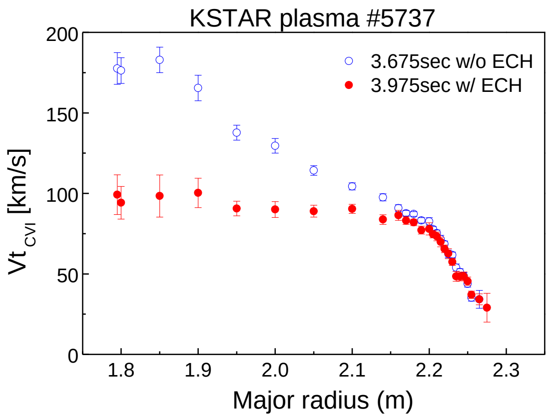

Fig.2.The effect of ECH on-axis heating on toroidal rotation

3.2 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.

The toroidal rotation velocity from CES decreased when n=1 RMP was applied and there is ELM mitigation region. We compared toroidal rotation profiles between during ELM and during ELM mitigation. The whole toroidal rotation during ELM is higher than that during mitigation and rotation damping rate is the same. Toroidal rotation speed is recovered when ELM starts to appear.

There is a little change of pedestal slope of toroidal rotation speed profiles compared to that without ELM mitigation. Steeper ion temperature pedestal can result in stronger intrinsic torque and higher central rotation. The experimental observation is a linear proportionality between rotation velocity and ion temperature pedestal gradient but it is not clear relation between rotation speed and density gradient in our case because we have no density profile. We must check very carefully how RMPs modify Ti pedestal in next campaign and the detail physics study is ongoing.

3.3 Pedestal during inter-ELM

The temporal evolution of Ti and Vt profiles during an inter-ELM period is shown in figure 3. The Vt profile collapses immediately after the ELM burst but its pedestal is quickly increased and the whole profile continues to build up during the period until it collapses again at the next ELM burst. However, the reduced Ti pedestal remains almost the same after the ELM burst.

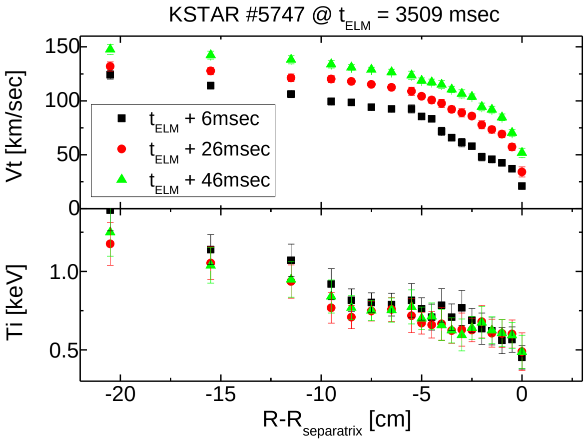

Fig.3. Temporal evolution of toroidal velocity and ion temperature profiles during an inter-ELM period of a type-I ELMy H-mode.

4. Conclusion

Since the first measurement of CES at the KSTAR device in 2010, the performance of CES has been gradually improved. The ion temperature and rotation velocity from CES make it possible to understand pedestal physics, ECH and RMPs effects, and ELM physics. Therefore, the KSTAR device including CES became prepared for contributing unsolved issues in thermonuclear fusion area.

The 4th campaign was focused on the control of ELM during H-mode. The ion temperature and rotation velocity were measured in the various conditions and the detailed analyses have been being conducted with other diagnostic results.

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