Plasma Velocity Profile During The Pulsed Poloidal Current Drive In The MST RFP Plasma

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Abstract. We report on the plasma velocity profile measurements during the pulsed poloidal current drive (PPCD) in the Madison Symmetric Torus (MST) reversed-field pinch (RFP). In order to decrease fluctuations due to dynamo activities, PPCD was applied to replace the dynamo electric field. As a result, the magnetic fluctuations have been further suppressed, and considerable increase of energy confinement has been already achieved. In the initial stage of PPCD, accompanying sudden reduction of both magnetic fluctuations and radiation from neutral deuterium atoms, the electron temperature increased rapidly. This improvement may be concerned with a current profile change to more stable region. For this change, we have studied whether plasma velocity profile changes To obtain the plasma toroidal velocity profile, we have measured the Doppler shift of several impurity lines. To make sure of the radial maximum emission location, line intensities for each impurity species have been measured at 10 poloidal chords. The data are inverted using MSTFit to obtain the radial impurity emission profile. As a result, a change of toroidal plasma rotation profile was unclear, since impurity ions shifted to r/a > 0.8 during PPCD.

INTRODUCTION

Reversed-field pinch (RFP) has attractive features as a fusion reactor, since the plasma is confined by weak toroidal magnetic fields. However, RFP plasmas are susceptible to large-amplitude magnetic field fluctuations due to dynamo activities. These fluctuations grow to an amplitude sufficient to cause reconnection and stochastization of the magnetic field lines, thereby degrading energy confinement. In order to decrease these fluctuations, a pulsed poloidal current drive (PPCD) was applied to replace the dynamo electric field in the Madison Symmetric Torus (MST) RFP (major and minor radii, R/a = 1.5/0.52 m) [1]. As a result, the magnetic fluctuations with poloidal mode number m = 1 and m = 0 have been further suppressed, and considerable increase of energy confinement has been achieved [2]. In the initial stage of PPCD, accompanying sudden reduction of both magnetic fluctuations and radiation from neutral deuterium atoms, the electron temperature increased rapidly [2]. Mostly, this sudden reduction is induced together with a small sawtooth crash. This improvement may be concerned with a current profile change to more stable region [3,4]. In tokamaks, H-mode confinement state has been sometimes related with a sawtooth crash [5]. Therefore, for this sudden change, we are attempting to measure spectroscopically the toroidal velocity component of the radial electric field in order to confirm or deny the probe measurements that were previously published [6]. It would be verified a hypothesis that a transport barrier due to a local velocity shear makes electron temperature further increase, and a reduction of the edge resistivity assists the current profile flatten. To obtain the plasma toroidal velocity profile, we have measured the Doppler shift of several impurity lines [7]. To make sure of the radial maximum emission location, line intensities for each impurity species have been measured at 10 poloidal chords. The data are inverted using MSTFit to obtain the radial impurity emission profile [8]. The measurement result of plasma velocity and ion temperature profiles during the initial stage of PPCD is described.

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EXPERIMENTAL SETUPS

In order to obtain a toroidal plasma velocity profile, we have measured the Doppler shift of several impurity lines using the ion dynamics spectrometer (IDS) precisely described in ref. 7. (Charge exchange recombination spectroscopy (CHERS) is not available for the toroidal plasma velocity measurement at the present.) This spectrometer is available to measure simultaneously impurity ion temperature and flow velocities with 10 μsec temporal resolution. This device is actually a duo-spectrometer: measurements from toroidally two different chordal views of the plasma can be made simultaneously via two separate quartz input fiber optic bundles coupled to the entrance slit of a spectrometer. We measured flow velocities and ion temperature for CV (227.1 nm), BIV (282.3 nm), OV (278.1 nm), CIII (229.6 nm) and HeII (468.6 nm) lines. Measurements are line-averaged along the toroidal viewing chord which samples the plasma from r/a = 0.3 to1.0.

To make sure of the radial maximum emission location, line intensities for each impurity species were measured at 10 poloidal viewing chords of r/a = -0.87, -0.58, -0.41, -0.24, -0.09, 0.10, 0.28, 0.45, 0.62 and 0.839. r/a = -0.87 and 0.839 chords are toroidally apart 120 degrees from other 8 chords. But this influence was taken into account in the analysis. Using two fiber bundles of the IDS system, line intensities for two chords were measured at one discharge. We measured CV (227.1 nm), BIV (282.3 nm), OV (278.1 nm) and HeII (468.6 nm) line intensities.

RESULTS

Plasma current was ~210 kA, and PPCD trigger timing was fixed at t = 9.0 ms. The SXR ratio (beryllium filter, 15 μm/7.5 μm) that corresponds to electron temperature increases after a sawtooth crash at t = ~11 ms as shown in Fig. 1(a). Figures 1(b) and (c) show time behaviors of magnetic mode fluctuations and H_α. After triggering of PPCD, single helicity state of toroidal mode number n = 6 (m = 1) is formed. After the final SXR crash (t = ~11 ms), both magnetic fluctuations and radiation from neutral deuterium atoms decrease. Hereafter, we pay attention to just before and after SXR crash, i.e., t = 10.5 and 13.5 ms.

Electron density profiles measured by a FIR interferometer are shown in Fig. 2. At t = 13.5 ms, electron density gradient becomes steeper at r/a ~ 0.7. Electron temperature gradient also becomes steep at r/a ~ 0.7 as shown in Fig. 7 of Ref. 2.

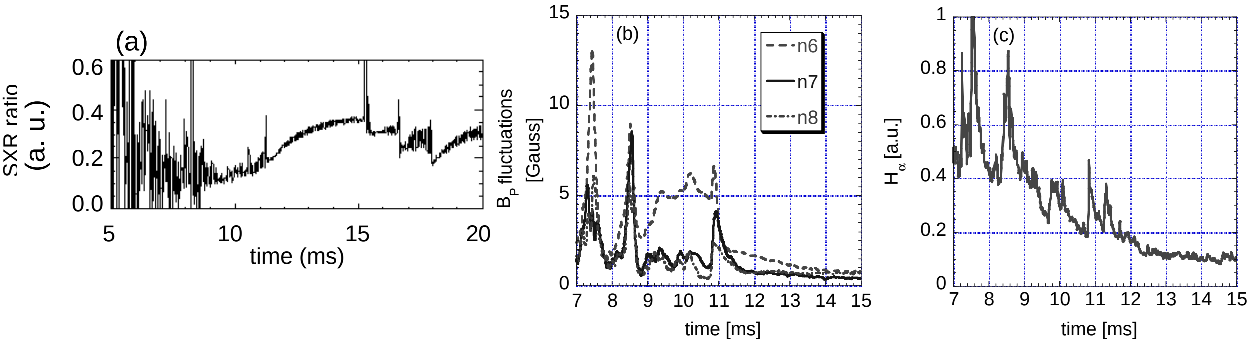

FIGURE 1. Time behaviors of (a) SXR ratio, (b) magnetic mode amplitudes of n = 6, 7 and 8, (c) H_α emission.

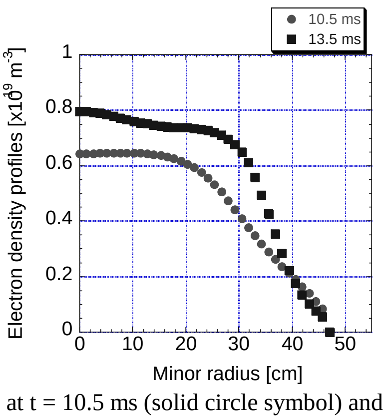

FIGURE 2. Electron density profiles at t = 10.5 ms (solid circle symbol) and 13.5 ms (solid square symbol), respectively.

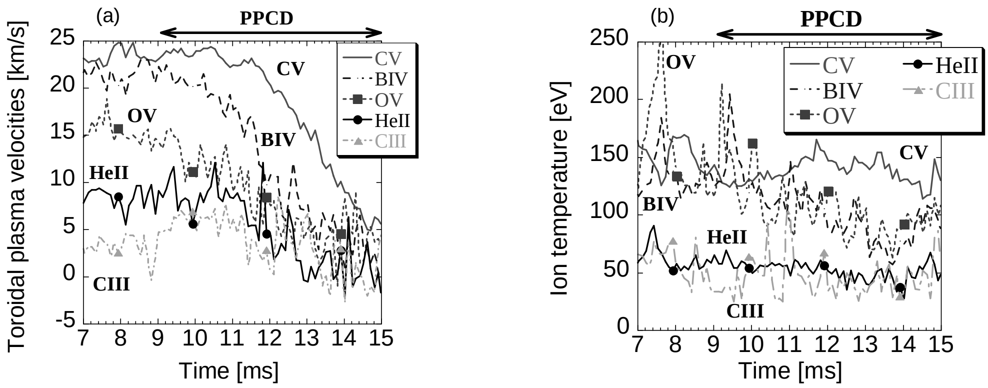

FIGURE 3. Time behaviors of (a) Toroidal plasma velocities, (b) ion temperatures. Solid line (CV), broken line with empty circle (BIV), dashed line with solid square (OV), solid line with solid circle (HeII) and dashed line with solid triangle (CIII).

Figure 3 shows measured toroidal plasma velocities and ion temperatures for CV, BIV, OV, HeII and CIII. 100 μs moving average and ensemble shot average were conducted. Toroidal plasma rotation decreased with PPCD. Ion temperatures of CV, HeII and CIII show almost no change. But ion temperatures of BIV and OV decrease with PPCD.

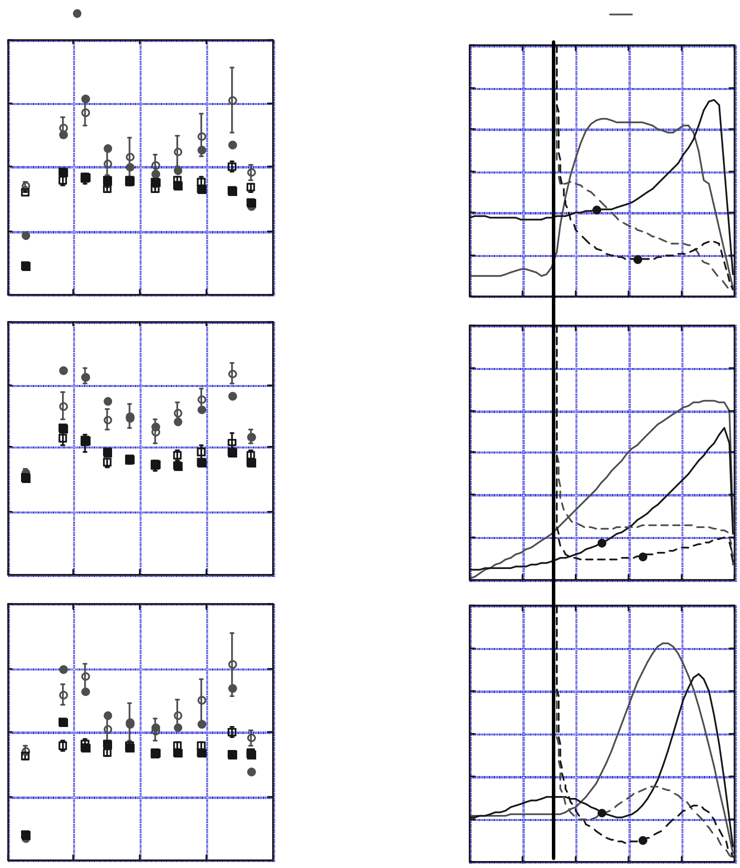

FIGURE 4. Line integrated emission profiles at t = 10.5 and 13.5 ms, (a) CV, (b) BIV and (c) OV. Inverted radial emission profiles and radial emission profiles multiplied by the appropriate geometric sensitivity function, (d) CV, (e) BIV and (f) OV.

Figures 4(a), (b) and (c) show line integrated emission profiles (empty symbols). Solid symbol data means inverse transformed data from Abel inverted emission profile (solid lines) shown in Fig. 4(d), (e) and (f). Inverted data fairly fits to the raw data as shown in Fig. 4(a), (b) and (c). Transformed emission profiles from line integrated emission intensities indicate the outward shift of the peak emission with increased electron temperature from PPCD as shown in Fig. 4(d), (e) and (f). During PPCD, since the equilibrium configuration drastically changes, we reconstructed the equilibrium of the MST RFP using MSTFit [8]. It provides rather good inversion of the line integrated emission. I*W curves (broken lines in Fig. 4(d), (e) and (f)) mean radial emission profiles multiplied by the appropriate toroidal geometric sensitivity function [9]. The outer peak of I*W curve indicates a main existing location of each species. Only for CV data, the raw data was divided by CV data from an another spectrometer, which was measuring the emission from a plasma center, in order to eliminate shot differences. Helium gas was puffed during the shot. But a strong asymmetric emission was measured, especially for the radial direction, since a puffing port was close to the used poloidal viewing chord. The inverted HeII emission looked ugly.

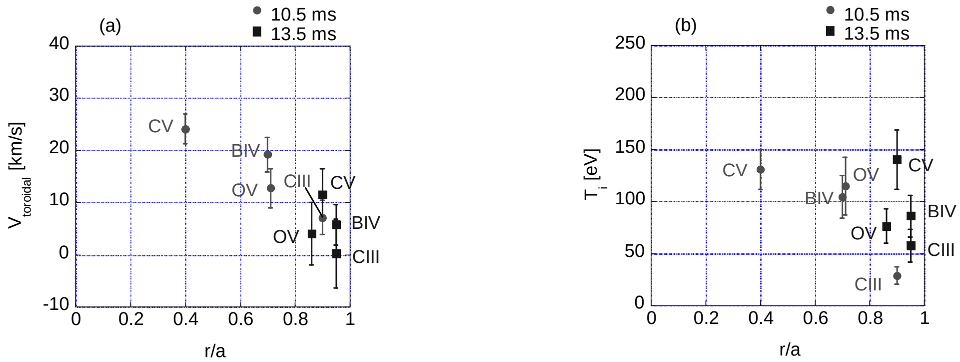

FIGURE 5. (a) Toroidal plasma rotation profiles, (b) ion temperature profiles at t = 10.5 and 13.5 ms. CV, BIV, OV and CIII data are listed. For CIII, *r/a* = 0.9 (t = 10.5 ms) and *r/a* = 0.95 (t = 13.5 ms) are assumed, respectively.

Figure 5(a) shows toroidal plasma velocity profiles. Measured species shifted to *r/a* > 0.8 during PPCD, and broadening of I*W curve corresponds to the error bar of the radial profile resolution. Therefore, the change of plasma rotation profile is unclear due to the insufficient spatial resolution. Figure 5(b) shows ion temperature profiles. It seems that ion temperature increases at the edge region in the case of PPCD. Ion temperature is higher than electron temperature at the edge region, nevertheless the magnetic fluctuations are suppressed. However, the conclusion of an increase of T_i in the edge really depends on the actual impurity location and the CIII assumption.

SUMMARY

In the initial stage of PPCD, accompanying sudden reduction of both magnetic fluctuations and H_α, the electron temperature increased rapidly. This improvement may be concerned with a current profile change to more stable region. Mostly, this sudden reduction is induced together with a small sawtooth crash. For this sudden change, we have studied whether plasma velocity profile changes. However, due to the insufficient spatial resolution, a change of plasma rotation profile is unclear. It seems that ion temperature increases at the edge region in the case of PPCD. However, the conclusion of an increase of T_i in the edge really depends on the actual impurity location and the CIII assumption. The hypothesis described in the introduction was not verified. Improvement of the spatial resolution using CHERS, and to study the correlation with local fluctuations for any frequencies are future problems [10]. Work was supported by USDOE.

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