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Pellet injection and confinement in the TPE-RX, Reversed Field Pinch

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Ice pellet injection experiment has been carried out in the TPE-RX, reversed field pinch (RFP) device. Significant plasma electron density (n_e) increase has been observed after the D_2 ice pellet injection into plasma with standard and pulsed poloidal current drive (PPCD) operation [1,2]. The pellet is injected into the plasma after 5 ms from the PPCD start. Due to the pellet injection, in the PPCD plasma the n_e becomes three times higher than in the standard plasma. The high n_e can be constantly maintained till the end of PPCD period (more than 15 ms).

The toroidal asymmetry of D-alpha emission is included into the discussion about particle confinement by using the toroidal D-alpha line intensity monitor system. Two chords CO_2/HeNe laser interferometer gives the radial electron density profile and the total number of particles, N. The estimation of the ratio of the N/I_α shows that the particle confinement is improved in the combination of the PPCD discharge and the pellet injection. Here, I_α indicates total D-alpha line intensity. The ratio N/I_α increases more than five times of the standard discharge. Since the N increases during the PPCD, this calculation is an underestimate and the actual particle confinement time should be larger. Thomson scattering measurement system shows plasma electron temperature. The electron temperature is well correlated with the soft X-ray intensity, I_{SX}. The I_{SX} is five times larger than in standard discharges. The increases of the N/I_α and I_{SX} strongly indicate the substantial improvement of the energy confinement.

Experimental results TPE-RX is one of the biggest reversed field pinch (RFP) machines, the minor radius a is 0.45m, and the major radius R is 1.72m. The plasma current and the toroidal field at the plasma edge are shown in Fig. 1. The red line shows the case of the combination of the PPCD and the pellet, the green line shows the case of the PPCD, and the blue line shows the case of the standard discharge. The maximum plasma current is 300kA in every condition. The pulse duration is about 80ms in the standard discharge, and is 35ms in the PPCD discharge. The PPCD is started at t = 18ms and is terminated at t = 35ms. The plasma electron density, n_{el} is measured by the dual chords CO_2/HeNe interferometer installed at 67.5 degrees from the pellet injector. The n_{el} is about 5 x $10^{18}m^{-3}$ as shown in Fig. 2. The n_{el}

is increasing during PPCD, and the n_{el} becomes 1 x $10^{19}m^{-3}$ at the end of the PPCD. The n_{el} in TPE-RX is lower than the other RFP devices using graphite in the vacuum vessel. Pellet injection is one of the possible methods to reach high-density operation. The ETA-BETA II pellet injector [3] has been installed in the TPE-RX. The pellet injector is a pipe gun type single pellet injector. One pellet is injected into the plasma during the discharge. The n_{el} measured with the central chord becomes more than 1.5 x $10^{19}m^{-3}$ after the pellet injection. The mass measured by the microwave cavity and the density increase are almost the same as the specifications of the injector [2]. The n_{el} decreases within several ms when the pellet is injected into the standard discharge. However, the n_{el} does not decrease during the PPCD when the pellet is injected into the PPCD discharge. The pellet is injected into the plasma at t = 24ms in this discharge. The pellet is broken into two pellets before reaching the plasma, and the n_{el} increase takes place in two steps. The high n_{el} is sustained for 15ms, when the pellet is injected at t = 20ms. It seems that the particle confinement is improved during the PPCD. The N is estimated assuming a density profile according to the function $\mathrm{n}(\mathrm{r}) = n_0\left(1 - r^{2\alpha}\right)\left(1 + Ar^{2\alpha}\right)$, and α = 2. Eleven Dα monitors are installed at the inner side port on the equator of the torus. The toroidal distribution of Dα emission is observed by the Dα monitor system as shown in Fig.3. The distribution is averaged over the 5ms. A position sensitive detector (PSD) measures the pellet trajectory and total Dα emission from the pellet. The Dα intensity at the pellet injection port (67.5degrees in Fig 3) is measured by the PSD. The asymmetry of the Dα emission is taken into account in the calculation of the particle confinement. The particle confinement is discussed using the Dα monitor and the total number of plasma particles. The

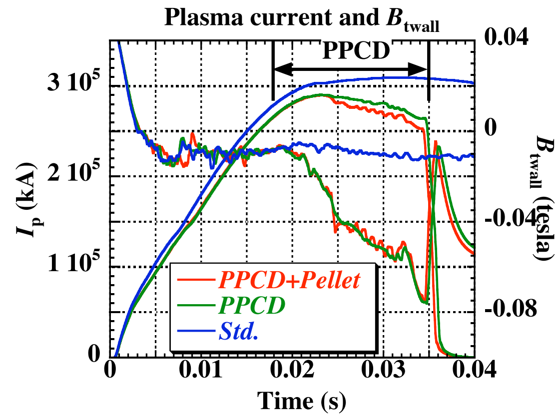

Fig.1 The plasma current and the toroidal magnetic field at the plasma edge. The PPCD started at t = 18ms.

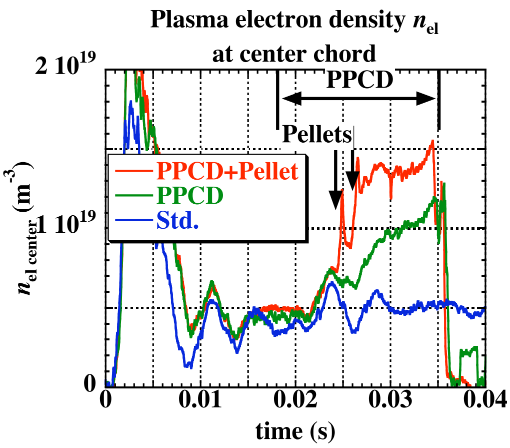

Fig. 2. Plasma density measured at center chord. The pellet is injected at t = 24ms. The pellet is divided into two pellets during transferring.

$N/I_{D\alpha}$ increases in the PPCD discharge as shown by the green line in Fig. 4. The maximum $N/I_{D\alpha}$ in the PPCD is 5 times of the $N/I_{D\alpha}$ in the standard discharge. This indicates that the particle confinement is well improved by the PPCD. The $N/I_{D\alpha}$ in the combination of the PPCD and the pellet also increases during the PPCD even if the $N/I_{D\alpha}$ decreases after the pellet injection. The $N/I_{D\alpha}$ in the combination of the PPCD and the pellet is usually smaller than the case of the PPCD without the pellet. However, the $N/I_{D\alpha}$ in the combination of the PPCD and the pellet is higher than the $N/I_{D\alpha}$ in the standard discharge. The particle confinement is well improved by the PPCD, and the high density operation with improved particle confinement is achieved by the combination of the PPCD and the pellet injection.

A Thomson scattering system has been installed at 112.5 degrees from the pellet injector since last year. The polychromator was installed with the assistance form the MST group. A Nd:YAG laser (10Hz) is directed vertically through the center of the plasma, and the T_e is measured at the center of the plasma. The discharge of the TPE-RX is about 80 ms, so T_e data of single location at the fixed time is obtained during one discharge. We measure the T_e at t = 32ms in these discharges. For the data shown in Fig. 3, T_e is 405eV in the combination of the PPCD and the pellet. The temporal behavior of the T_e in single discharge is not observed. The X-ray signal is well correlated with the T_e. The soft X-ray signal roughly indicates the temporal behavior of the T_e even if the X-ray signal has the dependence of impurities. The X-ray signal decreases rapidly after the pellet injection, and increases again as shown in Fig.5.

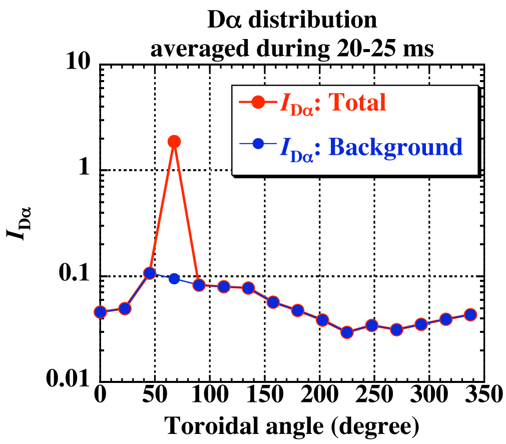

Fig. 3. Toroidal distribution of Dα emissions. The pellet injection port is at 67.5 degrees. The background emission at the 67.5 degrees is estimated using the background emissions at 45 and 90 degrees. The Da emission at 67.5 degrees is measured by the PSD.

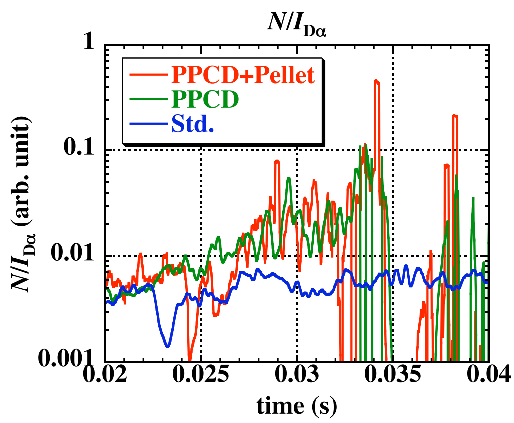

Fig. 4. $N/I_{D\alpha}$. N is total number of particles estimated from the density profile. $I_{D\alpha}$ is total Dα emission measured by the toroidal monitor and the PSD.

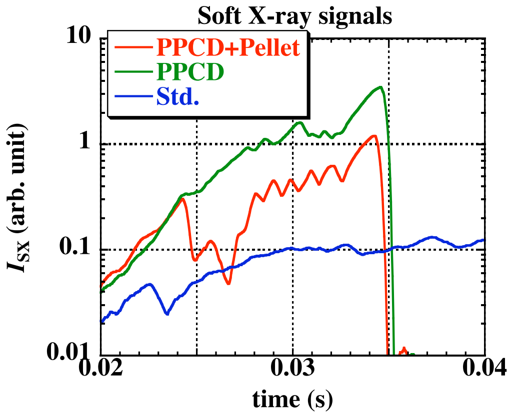

Fig. 5. Correlation between the I_{SX} measured by the SBD and the T_e measured by the Thomson scattering.

The X-ray signal is 5 times higher than the standard discharge even if it is smaller than the PPCD without the pellet. The T_e increases during the PPCD, and becomes higher than 800eV at t = 34ms. It seems that the T_e in the combination of the PPCD and the pellet injection also increases to the similar level of the PPCD without the pellet. The cooling effect of the fueling seems to be small. The variation of the magnetic fluctuations during the pellet injection is smaller than the variation between the different discharges. This also indicates that the pellet injection does not disturb the improvement during the PPCD discharge. We are still examining the calibration for the measurement system. It is to note that the absolute value of the T_e still includes some errors.

Summary High-density operation during the improved confinement is achieved by the combination of the PPCD and the pellet injection. The n_{el} increases three times higher than the standard discharge. The particle confinement is well improved at least five times by the PPCD. The pellet injection does not disturb the improved confinement by the PPCD. The T_e increases by the PPCD, and the T_e in the combination of the PPCD and the pellet injection also increases.

References

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