

## Pellet injection on TPE-RX

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**1. Introduction.** To control the density profile and to expand the operation region of TPE-RX (reverse field pinch device, minor radius,  $a=0.45$  m, and major radius,  $R=1.72$  m), pellet injection has been operated. The first wall of the TPE-RX is made by SUS, and the limiter is made by Molybdenum. Density in the standard discharge of TPE-RX is almost restricted by recycling from the first wall, and the density operation region is relatively lower than other RFP devices that use graphite tiles. Density in the standard discharge in TPE-RX depends on the plasma current, and increases up to  $1 \times 10^{19}$  ( $\text{m}^{-3}$ ) with increase of the plasma current up to 400 kA. Gas puff experiment [1] and magnetized plasma flow injection experiment [2] also have been carried out in TPE-RX. The gas puff experiment expands the operation region of the density to  $4 \times 10^{19}$  ( $\text{m}^{-3}$ ). However, the density increase is slow and the magnetic fluctuation increases by the gas puff.

Pellet injection has been used in order to fuel plasma particle source and control the density profile of fusion devices. In RFP, the first experiments of pellet injection were performed in ETA-BETA II and ZT-40M, and pellet injection was also used in TPE-1RM15 and RFX. Recently pellet injection has been performed in MST. Pellet injection was also used as a diagnostic tool in RFX [3]. ETA-BETA pellet injector has been installed on TPE-RX. The specification of the pellet injector is as follows. The mass of the pellet is  $2\sim 5 \times 10^{19}$  atoms and its velocity is up to 400 m/s. The obtained pellet is same as the specifications, and is injected into TPE-RX. Two-dimensional  $D\alpha$  measurement and pellet velocity measurement show the pellet trajectory in 3-D. This measurement shows the trajectory deflection of the injected pellet as expected. A Significant density increase due to the pellet is obtained both in standard and Pulsed Poloidal Current Drive (PPCD, [4]) discharges.

**2. Experimental results.** The pellet launched from the pellet injector goes through a light detector and a microwave cavity, and is injected into the plasma. The time of flight measurement between the light detector and the microwave cavity gives pellet velocity, and the microwave cavity gives pellet mass. Pellet trajectory is measured by one position-sensitive detector (PSD) [5]. The PSD measures the projection of the pellet trajectory on the

surface of a photo diode. The PSD is installed next to the launch nozzle looking at the pellet form behind, so the PSD measures only deflection of the trajectory. The trajectory in the radial direction is calculated from the pellet velocity. We also measure the pellet trajectory in the poloidal direction by a CCD camera from a tangential port. The view field of the CCD picture is narrow, but the picture of CCD helps to reconstruct the pellet trajectory. The PSD also gives the number of fueling particle by measuring  $D\alpha$  emission. Figure 1 shows the reconstructed pellet trajectory from the PSD signals. Figure 1 (a) and (b) show the reconstructed pellet trajectory for  $I_p=300$  kA discharge on a poloidal and toroidal cross section, respectively. The velocity of the pellet is 343 m/s, and the number of the ablated pellet is about  $9 \cdot 10^{19}$  atoms. The pellet penetrates into the center of the plasma with ablation. The pellet is injected into the plasma along the off-axis direction, and is deflected to the center of the plasma by the fast electron in the edge region.

Density is measured by a 2-chord CO<sub>2</sub>/HeNe interferometer installed toroidally 67.5 degrees away from the pellet injection section. The interferometer gives line averaged plasma densities through the center chord ( $r/a = 0.0$ ) and through the edge chord ( $r/a = 0.69$ ). The density and the  $D\alpha$  emission measured by the PSD for  $I_p=300$  kA discharge are shown in Figure 2. The pellet is injected into the plasma at  $t = 28$  ms, and  $D\alpha$  line is emitted impulsive

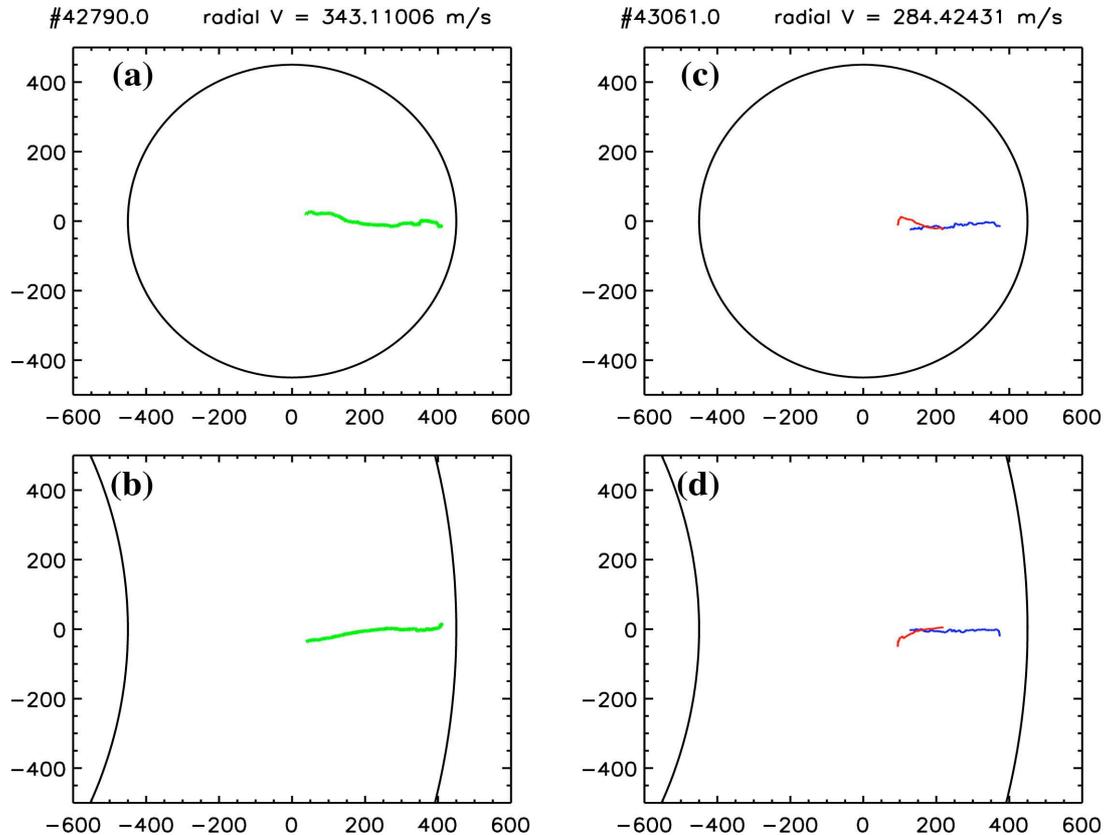


Figure 1. Reconstructed pellet trajectory for the standard discharge (a, b) and for the PPCD (c, d).

during about 1 ms. Density increases quickly at both measurement chords. The density profile becomes hollow after pellet injection, but soon recovers a peaked profile. The density at the center chord increases to  $1.5 \times 10^{19} \text{ (m}^{-3}\text{)}$  from  $0.5 \times 10^{19} \text{ (m}^{-3}\text{)}$ , and then decreases slowly.  $\text{D}\alpha$  emission is still visible during density decrease, but its intensity is quite low.

The pellet injection is also operated in the PPCD discharges. The pellet trajectory is shown in figure 1 (c) and (d). We have two pellets for this shot, and the second one penetrates into the core region as shown by the blue trajectory. Figure 3 shows density and PSD signal for the normal PPCD and for the pellet combination PPCD. PPCD starts at  $t = 18 \text{ ms}$  and terminates at  $t = 35 \text{ ms}$ . In the normal PPCD due to the improved confinement, the density increases slowly, and its profile becomes flat.  $\text{D}\alpha$  emission increases after  $t = 31 \text{ ms}$ , and then the density profile becomes hollow. In the pellet combined with PPCD, the density increases quickly after the pellet injection at  $t = 24 \text{ ms}$ . Density increases to  $1.5 \times 10^{19} \text{ (m}^{-3}\text{)}$  at the center chord and increases to  $2.7 \times 10^{19} \text{ (m}^{-3}\text{)}$  at the edge chord thus with a deep hollow profile. But shortly after pellet ablation, the density at edge chord decreases much faster than at central chord, indicating that the density profile becomes flat as in standard PPCD. Later on, however, the density at center chord does not change for 6 ms, and increases again as well as the normal PPCD. Density decreases to the level of normal PPCD before plasma terminated.

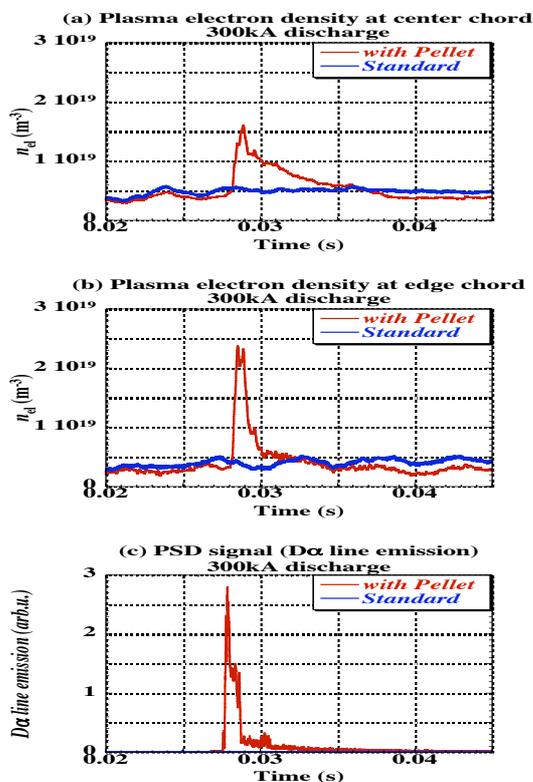


Figure 2. Density and PSD signal for the standard discharge.

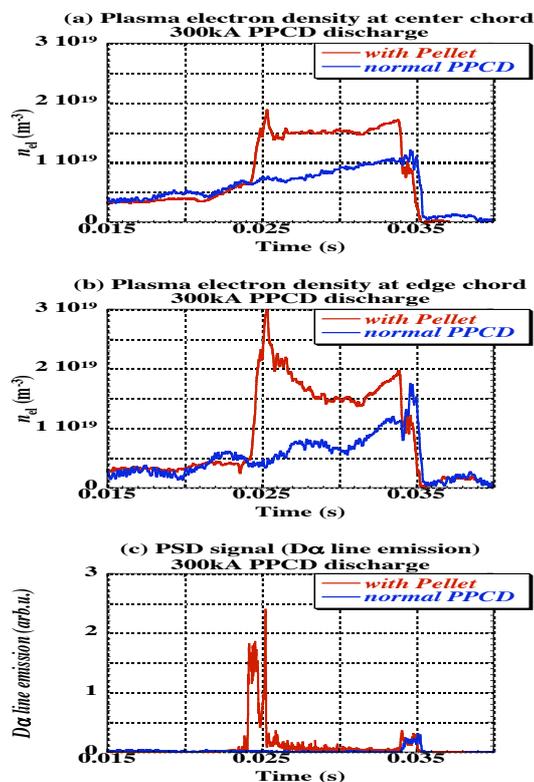


Figure 3. Density and PSD signal for the PPCD discharge.

The total number of particles is estimated from volume-integration of the profile function  $n(r)$ ,  $n(r)=n_0(1-r^4)(1+Ar^4)$ . Two measurement chords of interferometer give center density,  $n_0$  and profile factor,  $A$ . For standard 300 kA discharge, the profile factor decreases to the condition before pellet injection soon, though it increases rapidly. Center density increases slowly for 3 ms and decreases to the level before pellet injection after 5 ms. For PPCD 300 kA discharge, the density profile becomes hollow just after pellet injection as shown in Figure 4(a). Central density increases slowly for 4 ms and the increased level is sustained until the end of the PPCD. After the increase of the central density, also the shape of the profile is maintained. The total number of particles is  $10^{20}$  atoms at  $t=30$  ms and twice larger than the normal PPCD. These results predict the good particle confinement during PPCD. The study of the transport and the particle confinement will be part of a future analysis.

**4. Summary.** Pellet injection has been operated in TPE-RX. The pellet is injected into the TPE-RX from a horizontal port. It has been shown that the pellet is deflected in the plasma current direction at plasma edge and goes towards plasma center. It is considered that the fast electrons ablate the pellet and the pellet trajectory is deflected as expected. Pellet injection was performed in standard and PPCD discharges at  $I_p=300$  kA. The density increases due to the pellet injection is more than two times that of standard plasma. The significant density increase in PPCD discharges is maintained for a long period.

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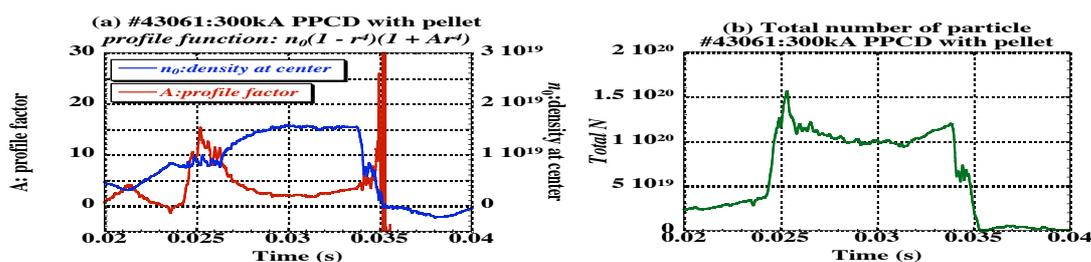


Figure4. (a):Profile factor  $A$  and center density  $n_0$ . (b):Total number of particle obtained by volume average of the profile function  $n(r)$ .