High-Beta Plasma Confinement in TPE-RX During Pulsed Poloidal Current Drive Operation in Reversed-Field Pinch Plasma

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A very high beta value was obtained during pulsed poloidal current drive (PPCD) operation in a reversed-field pinch (RFP) plasma during a TPE-RX experiment. Poloidal beta is almost equal to total beta in the RFP, and is as high as 30% near the end of PPCD operation. During the PPCD operation, the magnetic fluctuation associated with the dynamo effect is reduced, and improved confinement is realized, which results in this high beta value.

Keywords: reversed-field pinch (RFP), pulsed poloidal current drive (PPCD), high-beta plasma

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It was observed that the confinement property of reversed field pinch (RFP) plasmas is greatly improved by pulsed poloidal current drive (PPCD) operation. The PPCD operation drives the poloidal plasma current to sustain reversal of the toroidal field with one-turn poloidal loop voltage, which is induced by rapid step-wise deepening of the toroidal magnetic field at plasma surface [1].

In RFP, the direction of the toroidal magnetic field at the plasma surface (B_{ta}) is reversed with respect to that at the plasma center. This relatively complicated magnetic field configuration is realized by a poloidal current flow in the plasma [2]. Only a toroidal one-turn voltage can be applied by the flux swing in the torus core during the sustaining phase of the standard RFP operation. Therefore, only the toroidal current can be maintained by the electric field. The poloidal current, which is necessary for sustaining the reversed toroidal magnetic field configuration, is maintained by the so-called dynamo action. This action can produce the desired electric field through nonlinear coupling between plasma velocity fluctuations and the magnetic field. However, this magnetic fluctuation may destroy the magnetic surface, and the magnetic field lines may become stochastic, resulting in insufficient plasma confinement in RFP.

By PPCD operation, the poloidal current can be directly driven by the induced poloidal loop voltage, and the magnetic fluctuation level for dynamo action is reduced, resulting in an possible improvement in plasma confinement. This possibility has been confirmed by several experimental results. High temperature, good confinement, and high beta values can be obtained in some cases during PPCD operation in several RFP experiments [3–5].

TPE-RX is the one of the three largest RFP machines being operated in the world; it has major and minor radii of 1.72 and 0.45 m, respectively, a maximum designed current of 1 MA (it is currently being operated at less than 500 kA due to limitations in the power supply) and a discharge duration of about 100 ms [6]. PPCD operation has been attempted in TPE-RX, and the waveform of the stepping down of B_{ta} was successfully optimized for obtaining improved plasma performance; currently, six B_{ta} steps are being used.

Typical examples of waveforms of B_{ta}, externally applied toroidal magnetic field ($B_{t\text{-}out}$), plasma current (I_p), averaged toroidal magnetic flux ($\langle B_t \rangle$), and intensity of soft X-ray emission (I_{sx}) are shown in Fig. 1.

A sharp increase in I_{sx} is observed near the end of the

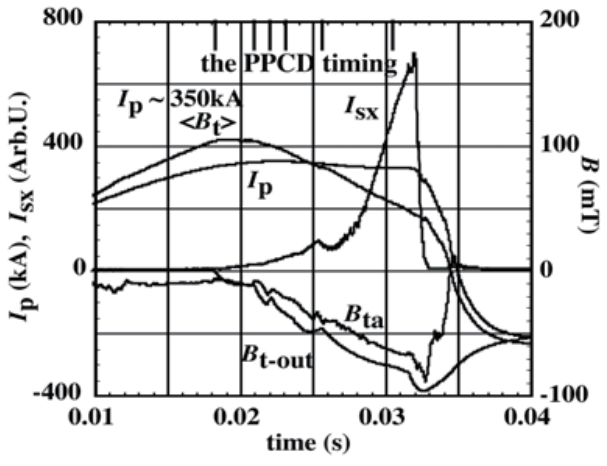

Fig. 1 Waveforms of I_p, $\langle B_t \rangle$, B_{ta}, $B_{t\text{-}out}$ and I_{sx} during PPCD.

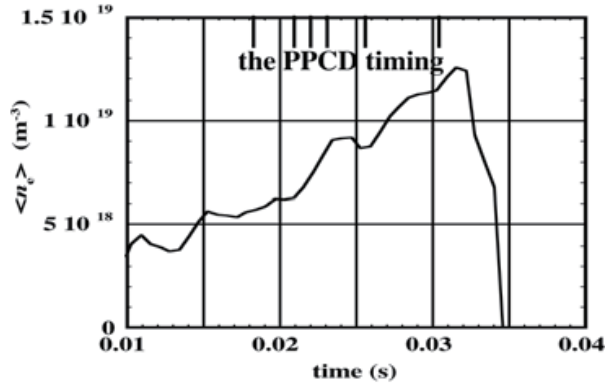

Fig. 2 Waveform of line averaged electron density during PPCD.

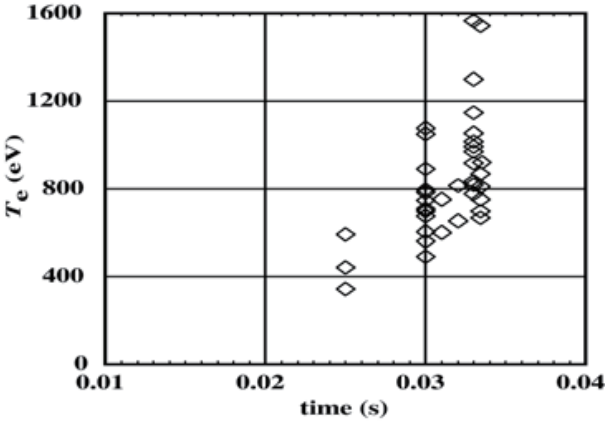

Fig. 3 Central electron temperature during PPCD.

PPCD operation period. I_{sx} becomes 30-50 times higher than that of standard discharge with the similar I_p.

The line-averaged electron density ($\langle n_e \rangle$) measured by the interferometer also exhibits a rapid increase during PPCD, as shown in Fig. 2, which becomes almost two times higher than that of an standard shot near the end of PPCD. Simultaneously, the radiation corresponding to the D_α line decreases significantly. This indicates a substantial increase in particle confinement time almost 10 times more than that of the standard shot [7].

Recently, the electron temperature at plasma center (T_e) was measured by Thomson scattering with a YAG laser during a PPCD period with $I_p \sim 350$ kA. The results are shown in Fig. 3; a similar rapid increase in T_e with $\langle n_e \rangle$ is shown, and T_e as high as 1.5 keV was obtained at the peak.

The time variations of poloidal beta (β_p) defined as

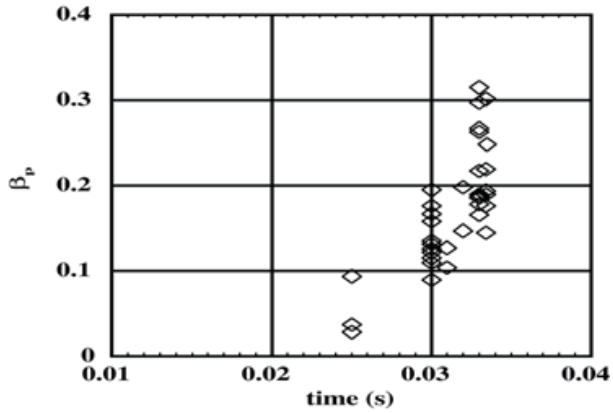

Fig. 4 Time variation of poloidal beta during PPCD.

$2\langle n_e T_e \rangle / (B_{ta}^2 / 2\mu_0)$ are shown in Fig. 4; here, we assume $T_e = T_i$ (ion temperature). β_p is about 5% before PPCD, and increases to nearly 30% close to the end of the PPCD period, despite the assumption that T_i is equal to T_e before PPCD. Increases in both T_e and $\langle n_e \rangle$ contribute to the attainment of this very high β_p value.

Analysis of the RFP reactor indicates that a reactor design with a realistic I_p value and confinement property could be possible when a β_p value higher than 20% is realized [8]. A higher β_p is preferable because it results in a design with lower I_p. A β_p value of ~30% can be considered as a milestone in the development of RFP research.

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