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Progress in the Pulsed Poloidal Current Drive in the TPE-RX Reversed-field Pinch Device

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1. Introduction

Recent progress made in the Pulsed Poloidal Current Drive (PPCD) [1] experiment in the Toroidal Pinch Experiment RX (TPE-RX) reversed field pinch (RFP) machine (R/a = 1.72/0.45 m, R and a are major and minor radii, respectively) is reported. It is shown that the energy confinement τ_E increased by a factor of five by using the double-pulsed operation of the new PPCD system.

The PPCD is a technique to induce the poloidal electric field in RFP plasma, and to drive the poloidal current, which is otherwise driven by the 'dynamo' activity. The PPCD can eventually suppress the intrinsic dynamo activity, which is caused by tearing instability, and the confinement is improved from that in the standard operating condition. Thus, the PPCD provides one of the improved confinement modes. The PPCD experiment was originated in the Madison Symmetric Torus (MST) in Univ. of Wisconsin [1]. Since then, several experiments have been carried out [2-5]. A recent PPCD experiment in MST has achieved a tenfold improvement in energy confinement time, τ_E and a record-high τ_E of 10 ms was obtained [3]. The PPCD was also tried in the Reversed Field eXperiment (RFX) and a twofold improvement in τ_E is reported [4].

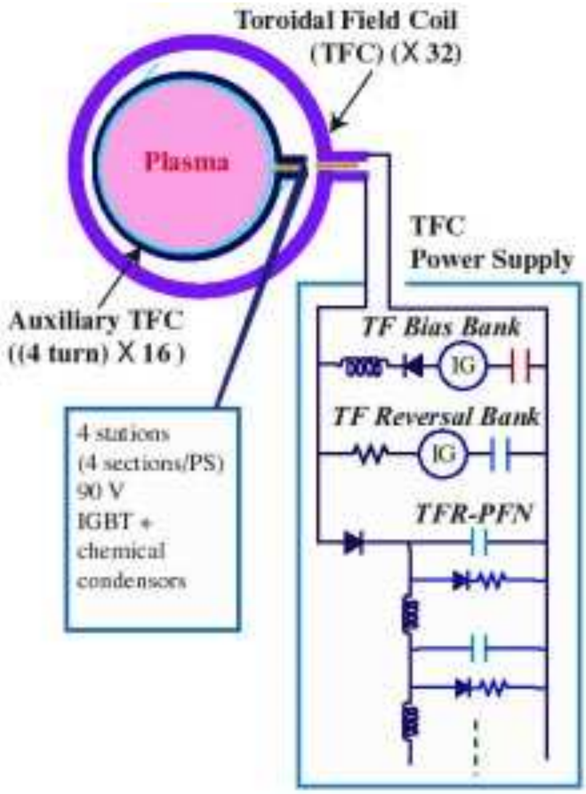

Figure 1. PPCD circuit in TPE-RX

A single-pulsed operation of the PPCD (s-PPCD) was performed in TPE-RX by using a toroidal reversal bank system, and the result showed a twofold improvement in the poloidal beta, β_p, and τ_E [5]. Recently, an additional toroidal coil and its power supply system were installed and a double-pulsed operation of the PPCD (d-PPCD) has become possible. The first report of the d-PPCD in TPE-RX is presented here.

2. D-PPCD experiment

The power supply system used for the PPCD in TPE-RX is shown in Fig. 1.

The PPCD operation is made by transiently deepening the toroidal reversal magnetic field, which gives a finite value of $d\Phi_t/dt$ (Φ_t is the toroidal flux) and induces the poloidal electric field E_θ in a direction to drive a poloidal current density to enhance the original value in the edge region. In TPE-RX, the s-PPCD is conducted by triggering a toroidal reversal (TFR) bank well after the formation of the RFP configuration. Before triggering the TFR, toroidal reversal is maintained by the current in the vacuum vessel, which is induced by the $d\Phi_t/dt$ term driven by the rump-up of the plasma current. By using this technique, the triggering time for the TFR bank is no later than 20 ms after the start of the plasma current. Toroidal reversal crosses zero beyond this time point unless the TFR is triggered. The s-PPCD by using the original energy of the TFR bank could drive the E_θ in 4 ms, and it yielded a twofold improvement in β_p and τ_E [5].

After the first PPCD experiment in TPE-RX, the energy of the TFR bank was increased, and the PPCD period was prolonged from 4 ms to 10 ms. Recently, additional toroidal field (TF) windings were installed at 16 poloidal sections with an independent power supply system for each of them. This additional TF system was originally developed to rotate the locked mode in TPE-RX [6]. The system can be used as a single pulsed PPCD if triggered simultaneously. Triggering the additional TF system first and the TFR bank second facilitates the d-PPCD operation, which enables a total PPCD period of more than 10 ms. Optimization of the d-PPCD operation was conducted as follows. The operating conditions for the d-PPCD, such as the triggering time for the two independent power supplies as well as the charging volts for those capacitor banks, are optimized so that the peak and the duration of the soft X-ray signal, I_{sx}, become as large and long as possible. In general, the soft X-ray signal reflects the electron temperature and density. It is confirmed from the comparison of the soft X-ray signal that the d-PPCD yields larger intensity than the s-PPCD. The best performance is obtained at the plasma current, I_p = 350 kA for the present energy in the d-PPCD power supplies.

Figure 2 shows shot averaged waveforms of the d-PPCD experiments with solid curves in comparison with those in the standard discharges with dashed curves. The charging voltage of the start-up capacitor bank for I_p in the d-PPCD is the same as that in the standard case, while that of the flat-top bank is switched off in the d-PPCD, which gives a larger and well sustained I_{sx} than the case with a finite charging voltage for the flat-top bank. This is the reason why I_p in the d-PPCD is smaller and the total pulse duration is shorter than the case in the standard discharge. This situation is seen in the waveform of V_{loop} in Fig. 2, and is consistent with the latest PPCD operation in MST [3] where $E_{//}$ is kept in the PPCD direction.

The waveform of V_θ in Fig. 2 shows a double-pulsed operation which lasts for 10 ms with $V_\theta > 0$. The reversal and pinch parameter, F and Θ, show large change of the RFP configuration during the PPCD period. It is shown that I_{sx} becomes an order of magnitude larger than that in the standard case. The peak of I_{sx} is reached at the end of the PPCD period when V_θ crosses zero to the anti-PPCD polarity and a relaxation event usually happens. The line averaged electron density, n_{el}, increases during the PPCD period by a factor of 1.8, and the central electron temperature, T_{e0}, from the Thomson scattering becomes larger by a factor of 1.7 than the standard case. The ion temperature, T_i, is measured by a neutral particle energy analyzer, and T_i also increases after the triggering of the PPCD and has a peak after the end of the PPCD period at $t \sim$ 36 ms. It is speculated that the increase of T_i during the PPCD is due to the improved ion confinement and that after the PPCD period is due to the increased ion heating power through the enhanced fluctuation in the post PPCD period.

From these observations shown in Fig. 2, β_p and τ_E are estimated to be 0.17 and 2.8 ms at t = 29 ms of the d-PPCD case, respectively. The increment factors of β_p and τ_E from those in the standard case are 3.2 and 5.1, respectively. Note here that τ_E is evaluated from, W_s / P_{oh}, where the ohmic input power P_{oh} is calculated

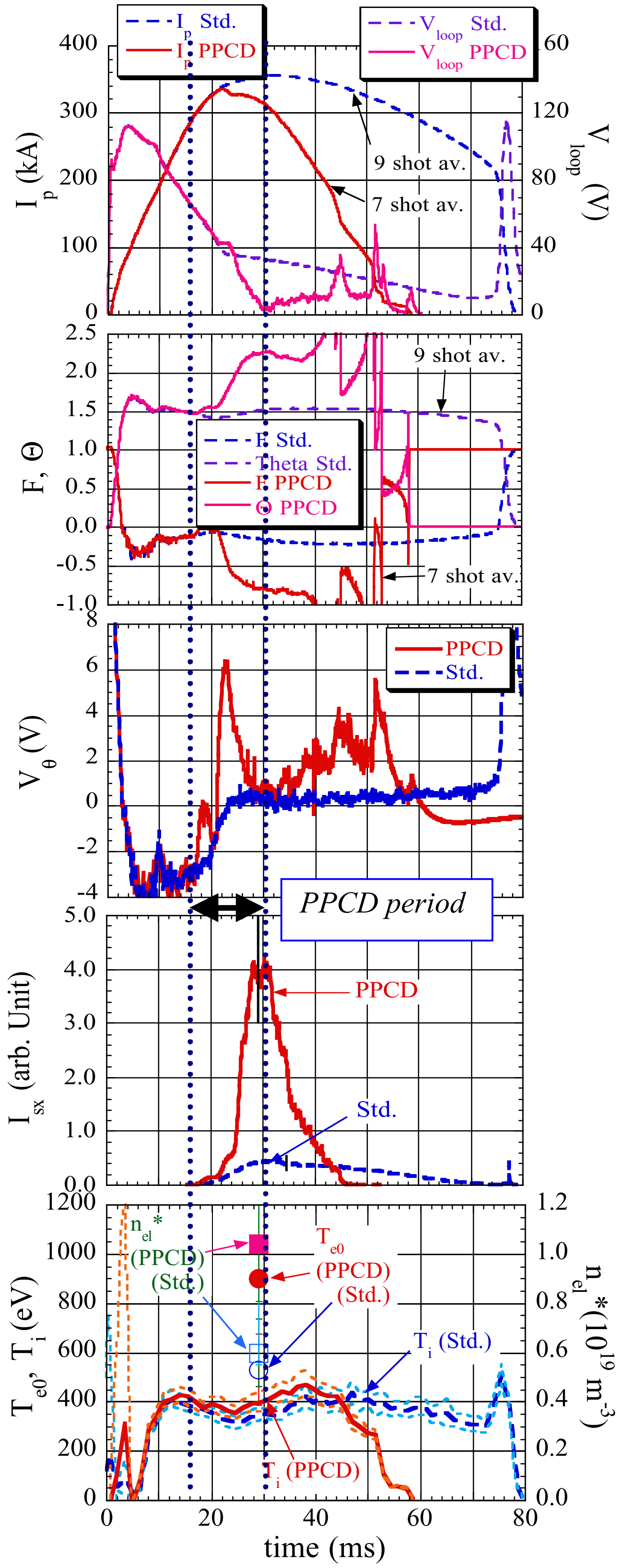

Figure 2. Comparison of the shot-averaged waveforms in the d-PPCD and the standard discharges

through α-Θ0 model [7] and W_s is the stored energy calculated assuming $n_e = n_i$ and constant spatial profiles of $(1-(r/a)^3)$ for $n_e(r)/\ n_{e0}, T_e(r)/T_{e0}$, and $T_i\ (r)/\ T_{i0}$. Note that $dW_s\ /dt = 0$ is assumed at $t = 29$ ms when I_{sx} has a peak.

Preliminary analysis shows that the fluctuation amplitude during the PPCD decreases as shown in the s-PPCD case [5]. Quantitative analysis for the mode amplitude is underway.

3. Database of the PPCD experiments and common trend

The database of the PPCD experiments has been enriched. There have been five PPCD experiments [1-5] and the present work provides another data. Comparison of the results enables us to extract some common features and trend of the PPCD experiments. One of them is that the improvement factor of τ_E scales with δb^{-2} where δb is the magnetic fluctuation amplitude relative to the standard case [5]. Another trend is plotted in Fig. 3. The enhancement factor of τ_E increases with Δγ, where Δγ is the difference in γ [=(1-*F*)/Θ] between the start and the end of the PPCD period. These results indicate that following a *F*-Θ trajectory, which increases Δγ, leads to a more stable path and larger energy can be stored under the high Θ (high magnetic shear) configuration.

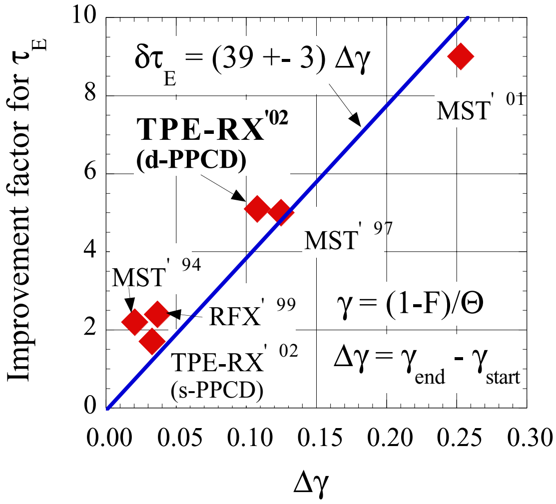

Figure 3. Figure of merit of the PPCD operation

4. Summary

Recent progress made in the PPCD operation in a reversed field pinch machine, TPE-RX, is reported. Double pulsed operation (d-PPCD) leads to a longer PPCD period (10 ms) than that in the single-pulsed operation. The d-PPCD yields a threefold improvement in β_p and a fivefold improvement factor in τ_E. The PPCD database shows that the enhancement of τ_E in the PPCD is larger when Δγ is larger and δb^2 is smaller.

References

[1] Sarff J S et al, 1994 *Phys. Rev. Lett.* **72** 3670.

[2] Sarff J S et al, 1997 *Phys. Rev. Lett.* **78** 62.

[3] Chapman B E et al, 2001 *Phys. Rev. Lett.* **87** 205001.

[4] Bartiromo R et al 1999 *Phys. Rev. Lett.* **82** 1462.

[5] Yagi Y et al, 2002 *Plasma Phys. and Control. Fusion* **44** 335.

[6] Hirano Y et al, 2002 *EPS29 (this conference) P-1 092*.

[7] Antoni V et al, 1986 *Nucl. Fusion*.**26** 1711.