AN INTERPRETATION OF THE IMPROVED CONFINEMENT IN HIGH PINCH PARAMETER PLASMA OF TPE-1RM20 WITH THE FIRST RESULT OF TPE-RX

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1. Introduction

Recent experimental studies in reversed field pinch (RFP) devices have revealed several improved confinement modes. Improved High Theta Mode [1] found in TPE-1RM20 is one of them, showing a factor of two confinement improvement. Enhanced Confinement mode (EC) in MST, Pulsed Poloidal Current Drive (PPCD) in MST and RFX also showed confinement improvement up to by a factor of about five in PPCD on MST. This paper provides additional experimental observations concerning high Θ scanning in the previous TPE machines in comparison with the so called improved mode in TPE-1RM20. We show one of the possible interpretations of the physics causes of the improvement seen in TPE-1RM20. It might have a common key to understand the improved modes in other RFPs.

The paper also provides the first report on the experimental results of the new large RFP machine at ETL called TPE-RX (R/a = 1.72/0.45 m, b/a = 1.08) .

2. Potential improvement in high Θ plasma and its necessary conditions

Improved confinement in high pinch parameter (Θ) plasma region was found in TPE-1RM20 and reported in refs. [1]. In short, the improved confinement in TPE-1RM20 is characterized by a spontaneous appearance of the large sawtooth free discharges in high Θ region where Θ ≈ 1.7-2. Global confinement parameters such as electron density, poloidal beta, β_p, and energy confinement time, τ_E, are improved by a factor of two, and a maximum τ_E of 0.6-0.8 ms was obtained at Θ ≈ 2 with the plasma current I_p = 130 kA. However, the physics cause of the improvement was not clearly understood, though several candidates concerning the operation and conditions of the machine have been pointed out such as wall conditioning, constant theta operation by having slightly decaying plasma current, smaller input power compared with TPE-1RM15 for the same I_p and shell proximity. Among them, this paper points out that shell proximity might be one of the necessary condition for it.

We collected Θ scan experiments at I_p = 130 kA from the three RFP configurations at Electrotechnical Laboratory; TPE-1RM15 (R/a = 0.7/0.137 m, b/a = 1.18), TPE-1RM20 (R/a = 0.75/0.192 m, b/a = 1.08) and TPE-1RM20mod (R/a = 0.75/0.192 m, b/a = 1.12), where R, a, b are major and minor radii of the plasma and minor radius of the inner most conducting shell. Figure 1 shows τ_E vs. Θ for the three configurations. Since the absolute values of τ_E cannot be comparable among different size of the plasma since the transport should scale with the size, only qualitative tendency as a function of Θ should be compared in Fig. 1. The experiment in TPE-1RM20mod was conducted by taking out of the double layered thin shell from TPE-1RM20 [2]. More than 100 of main discharge cleaning shots were conducted in

TPE-1RM20mod to recover wall condition after couple of months of opening period. It is still possible that the result shown for TPE-1RM20mod in Fig. 1 might be affected by a different wall and/or vacuum condition from other two configurations. Concerning plasma parameters for the three devices, line averaged density is 1.7 ± 0.4, 1.0 ± 0.1, 1.4 ± 0.1 × 10^{19} m^{-3} for TPE-1RM15, 20 and 20mod, respectively, while central electron temperature is in the range of 540-600 ± 200 eV for all devices.

Having these experimental situations in mind, we note from Fig. 1 that the conspicuous improved confinement in high Θ region was only observed in the original shell configuration of TPE-1RM20 which had the best shell proximity of b/a = 1.08. We speculate that the shell proximity can be a necessary condition for the improvement in high Θ discharges. Wall conditioning can also be of importance because it could affect the plasma stability through the change of current density profile. However, since the Θ-scan in TPE-1RM15 was conducted in a similar wall condition to TPE-1RM20, wall conditioning may be a sufficient condition rather than a necessary condition for the improved high Θ discharges.

A numerical stability analysis of a MHD code as a function of the shell distance at Θ = 1.7 also shows an increase of the linear growth rate of the axis resonant tearing mode and an appearance of the internally non-resonant mode at $b/a \approx 1.15$. This indicates that the shell proximity better than the critical threshold for the resistive shell modes would lead to a large sawteeth crash free discharges in high Θ region. It can be speculated that τ_E would increase not only by the increase of the stored energy through the reduced transport but also by the non-enhanced input power through the non-enhanced or even reduced $\boldsymbol{v}\times\boldsymbol{b}$ dynamo activity.

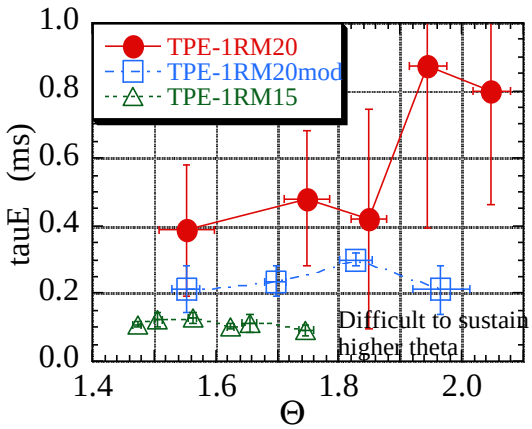

Fig. 1 Tendency of tauE with theta for three different machines.

3. First Result of TPE-RX

TPE-1RM20 was shutdown in Dec. 1996, and the construction of the next-step, larger RFP machine called TPE-RX started since then. Construction of the TPE-RX was complete with the first plasma on 25-Dec.-1997. TPE-RX has major and minor radii; R/a = 1.7175 / 0.45 m and shell proximity; b/a = 1.08. It is designed for the maximum I_p of 1 MA for 100 ms. TPE-RX aims optimization of the energy confinement time up to 1 MA plasma current. The idea of the interpretation of the improved confinement in high Θ region, as described above, will be also tested in this new machine. The machine is characterized by the good shell proximity, plasma equilibrium control by the DC vertical field, error field compensation by way of the same concept as TPE-1RM20 and all metal first wall with molybdenum fixed limiters.

After obtaining the first plasma, we continued adjustment and test of the coil systems with preparation for diagnostics. Then we conducted about 2200 shots of Taylor discharge

cleanings with hydrogen for half a month in February 1998. The first RFP configuration was successfully obtained on 5th of March with I_p = 100 kA and the discharge duration time, τ_d, was 50 ms. Consecutive 800 shots of RFP discharge cleanings with hydrogen reduced the non-inductive loop voltage from 22-25 V to 17-19 V. It still shows decaying tendency, indicating necessity for further wall conditioning. Then optimization of the operating condition, especially with DC vertical field for plasma equilibrium control was tried in April. In May and June, we continued more than 600 shots of RFP main discharge cleanings mainly at I_p = 250-300 kA with deuterium gas. Physics experiments on magnetic field distribution and plasma rotation measurement have already started.

The error field at the thick shell gap for these RFP discharges were compensated by the hybrid poloidal coil and by the feedback-controlled, local saddle coil at the gap position. Plasma equilibrium was passively maintained by the shell system and the no or small (0.0006 T) DC equilibrium control was applied for these cleaning discharges. Since the toroidal bias magnetic field and the pulsed vertical field for the cancellation of the pre-soaked DC vertical field inside the shell are not yet sufficient with the present power supplies, the operation region with the DC vertical field is still narrow to scan up to the designed equilibrium position of the plasma. However, preliminary experiment with the DC equilibrium magnetic field up to 0.0033 Tesla for I_p = 250 kA discharges has shown that the loop voltage does not change with the DC vertical field which causes the inward shift of the column. This is somewhat different from our previous experience [3]. Note that the axis of the vessel and the double layered thin shell system is shifted outward from the thick shell axis so that the axis of the outermost flux surface coincides with the vessel axis only with small DC vertical field (0.0036 Tesla for I_p = 250 kA for the equilibrium with the thick shell). We need to repeat this experiment after sufficient wall conditioning with larger operation region for the DC vertical field together with the diagnostics for the equilibrium magnetic field.

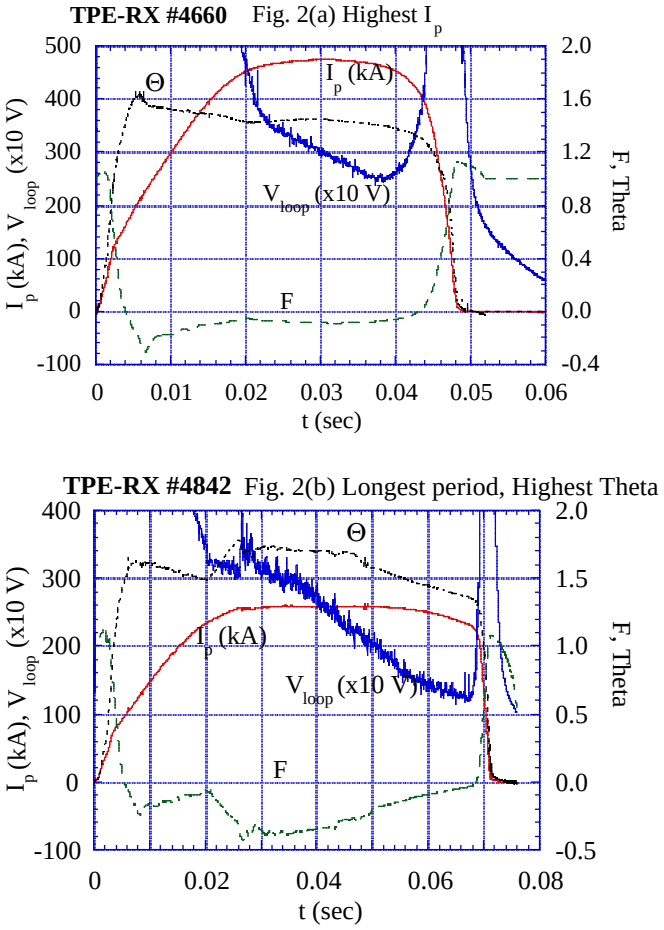

Fig. 2 Examples of the present operating limits of TPE-RX

Most recently, after exploring present operating capability of the machine, we have obtained so-far the highest I_p shot and the longest τ_d with highest Θ shot as shown in Fig.

2(a) and (b), respectively. The maximum I_p of 480 kA was obtained with 90% / 80% charging voltages for the poloidal start-up / flat-top capacitor banks. Since single flux swing is only capable at present, the shot of I_p ~ 0.5 MA shows the machine capability of reaching 1 MA with the double swing operation after installing a bias power supply for the iron core. Pulse duration time is presently limited by the capacity of the toroidal reversal PFN bank. It is shown in Fig. 2(b) that it is possible to prolong τ_d by delaying the trigger for the PFN and with the deeper toroidal reversal. The PFN will be upgraded in a year and 100 ms discharge will be realized. Note that deuterium gas has been used since April and it is the case for Fig. 2 and 3.

Up to now, no measurement concerning global confinement properties, such as electron temperature and density, are available. Non-inductive loop voltage, R_pI_p, however, is available to foreseen the tendency of the global confinement with I_p and to watch the degree of the completeness of the wall conditioning. Figure 3 shows recent R_pI_p calculated from Polynomial Function Model at five different time points for I_p-scanning. It shows that R_pI_p has minimum just after the current rise (20-30 ms) where R_pI_p is almost constant with I_p. On the other hand, R_pI_p increases with time and the increment becomes larger with I_p, suggesting that larger PWI might be causing larger influx of impurity. We expect that more cleaning discharges will mitigate this increment of R_pI_p with time and I_p. Average value of R_pI_p at t = 27.5 ms of I_p = 250 kA is about 17 ± 3 V, which corresponds to the conductivity electron temperature (Z_{eff} = 1) of about 150 eV.

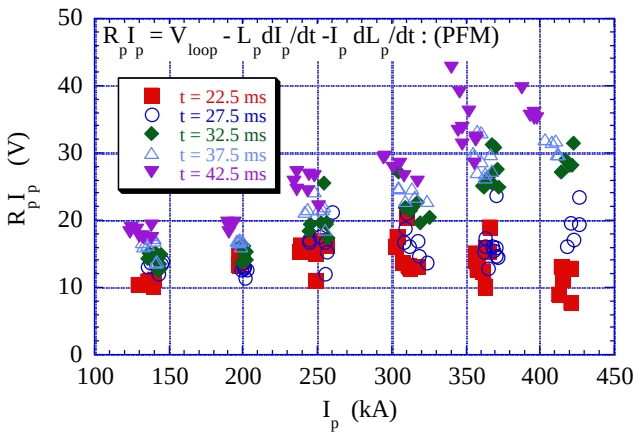

Fig. 3 Non-inductive loop voltage with I_p.

4. Summary

Shell proximity is raised as a candidate for a necessary condition for the improved high Θ discharges in TPE-1RM20 by comparing the Θ-scan in three different shell configurations. The first report on the experimental results of TPE-RX, a new large RFP at ETL, is presented. RFP configuration has been successfully obtained up to the limitation by the power supplies. The machine performance such as, I_p and τ_d , will be improved up to the specifications by installing necessary power supplies step by step as scheduled. Global confinement properties will be measured in several months after sufficient optimization and discharge cleanings.

References

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