IMPROVED CONFINEMENT REGIMES IN THE TPE-RX REVERSED-FIELD PINCH DEVICE

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1. Introduction

Improved confinement regimes in the TPE-RX reversed field pinch (RFP) device are investigated in comparison with the standard operating regime reported in [1]. In particular, result of the gas puffing experiment is reported in detail. The I/N value (I: plasma current (= I_p), $N=\pi a^2\langle n_e\rangle$, $\langle n_e\rangle$ is the volume averaged electron density) reaches to approximately 2 X 10^{-14} Am at the highest rate of gas puffing. Spatial profile of the electron density is speculated from the dual-chord interferometer system. It is shown that the poloidal beta, β_p, and energy confinement time, τ_E, are improved as I/N decreases, which is consistent with the tendency in other RFP plasmas. Radiation loss power is also evaluated as a function of I/N and I_p.

TPE-RX [2] is a large RFP machine with R/a = 1.72/0.45 m, where R and a are the major and minor radii, respectively. Global confinement properties under the standard operating conditions, at I_p < 0.5 MA, give the range of β_p = 5-10%, τ_E = 0.5-1 ms with relatively high I/N value of 12 X 10^{-14} Am [1]. The standard operating conditions are characterized by the discharges fueled by a steady flow of deuterium at Θ = 1.4-1.5 with a feedback-controlled gap-error compensation and with equilibrium maintained by the thick conductive shell, where Θ is the pinch parameter. Recently, we have been exploring several operating conditions which are different from the standard conditions, aiming to achieve improvement of the confinement properties. Status of these improved confinement modes is briefly summarized. Pulsed poloidal current drive (PPCD) [3] is one of them and the result at I_p = 300 kA gives twofold values of β_p and τ_E [4]. Another regime is the low I/N regime realized by means of the gas puffing technique. It has been commonly observed in many RFP plasmas, that β_p as well as τ_E increases as I/N decreases. From the recent gas-puffing experiments, we have also confirmed this tendency in the TPE-RX plasma. On the other hand, in order to know the energy balance under these operating conditions, radiation power loss is evaluated by means of a bolometer system, and the radiation fraction is quantified as a function of I/N and I_p.

2. Gas puffing experiment

The I/N value of the standard operating condition in TPE-RX is approximately 12 X 10^{-14} Am and constant with I_p [1]. It is possible to scan the electron density at a fixed plasma current by means of a gas puffing technique. Two gas puffing systems are installed on the vacuum vessel of TPE-RX with a toroidal separation of 180 degrees. A fast acting valve at each gas-puffing location is triggered at t = 20 ms, which is at the end of the current-rising phase. The electron density is scanned by changing the back pressure, P_{GP}, of the deuterium gas fuelled by the gas puffing systems, while keeping the acceleration voltage and a gate pulse width for the gas puff. The maximum P_{GP} ever tried is 400 kPa, which corresponds to 5000 Torr liter, approximately. Line-averaged electron density, n_{el}, is monitored by the dual-chord interferometer system [6] at r/a = 0 ($n_{el}(0)$) and 0.69 ($n_{el}(0.69)$). The Thomson scattering system measures the central electron temperature, T_{e0}, and density, n_{e0}.

When gas puffing is triggered, n_{el} increases in 10 ms and decays in an *e*-folding time of 25 ms in a typical case at I_p = 300 kA (Fig. 1). The global confinement properties are measured at t = 30 ms at which n_{el} has a maximum in time. It is shown in Fig. 1 that $n_{el}(0)$ can increase by a factor of 5 from that in the standard operating condition. However, we noticed that n_{e0} increases by a smaller factor than the increase ratio of $n_{el}(0)$, which may indicate that the electron density profile becomes hollow when gas puff is used. For simplicity, we assume following profiles of $n_e(r)$: $n_e(r) = n_{e0}\,(1 - x^{\nu})$ (Standard) and $n_e(r) = n_{e0}\,(1 - x^2)\,(1 + \alpha x^2)$ (Gas puffing), where $x = r/a$. We estimate ν and α from $n_{el}(0)$ and $n_{el}(0.69)$, while using relative change of n_{e0} in arbitrary unit obtained by the Thomson scattering to check consistency of the change of the profiles among the data with different back pressures for the gas puffing experiment. Note that the assumed profile for the gas puffing case has a hollow profile as long as $\alpha > 1$. The obtained profiles are plotted in Fig. 2 for the case at I_p = 300 kA. It is shown that $n_e(r)$ becomes more hollow as P_{GP} increases hence as n_{el} increases. It is also measured that $n_{el}(0.69)/n_{el}(0)$ increases with I_p and $n_{el}(0.69)/n_{el}(0) \sim 1$ at I_p = 400 kA. Details of the density profiles in TPE-RX is reported in [6].

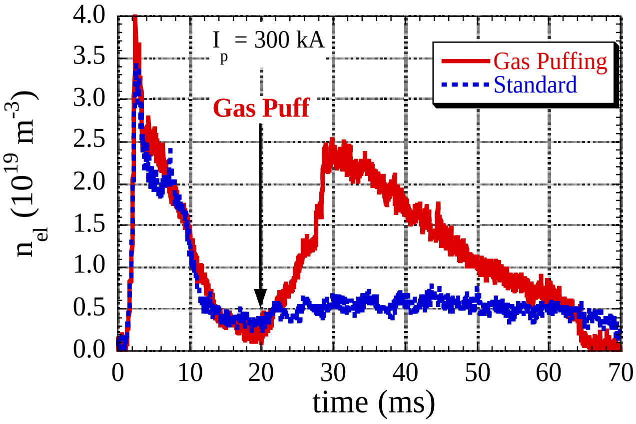

Figure 1 Comparison of the line averaged density between the standard and gas-puffing discharges.

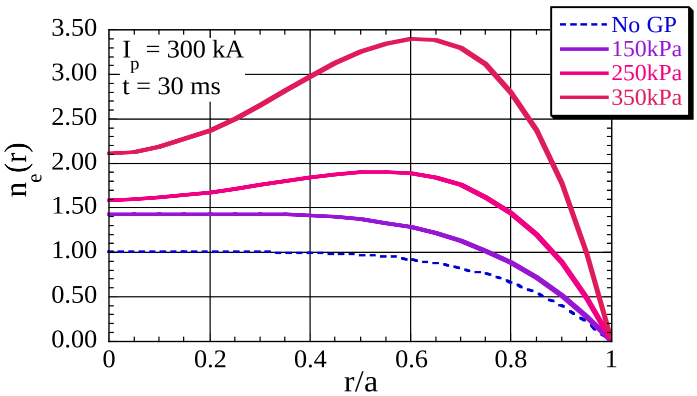

Figure 2 Profiles of the electron density.

Global confinement properties, β_p and τ_E, are obtained from T_{e0} and $n_{el}(0)$ with the following assumptions. Ion temperature, T_i, is assumed to be the same for the standard operation at I_p = 300 kA, i.e., T_i = 320 eV which was measured by the neutral particle energy analyzer. Ion density, n_i, is assumed to be the same as n_e including the profile as in Fig. 2. Electron temperature profile of $T_e(r) = T_{e0}\,(1 - x^3)$ is assumed. Figure 3(a) shows β_p versus I/N. The result shows that β_p increases as *I/N* decreases, hence as n_e increases. Note that the lowest *I/N* value is approximately 2 X 10^{-14} Am which is comparable to the lowest *I/N* values in RFX. Thus the gus puffing technique provides a wide range of *I/N* from 2 to 12 X 10^{-14} Am in TPE-RX. On the other hand, τ_E increases more moderately as *I/N* decreases (Fig. 3(b)). The highest τ_E obtained by gas puffing is 1.8 ms. Note, however, that the assumptions of the constant T_i as well as the fixed T_e profile are giving optimistic values for β_p and τ_E.

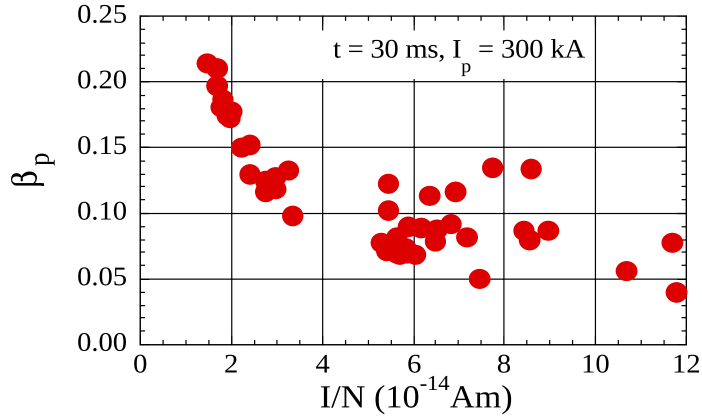

Figure 3(a) Poloidal beta versus I/N.

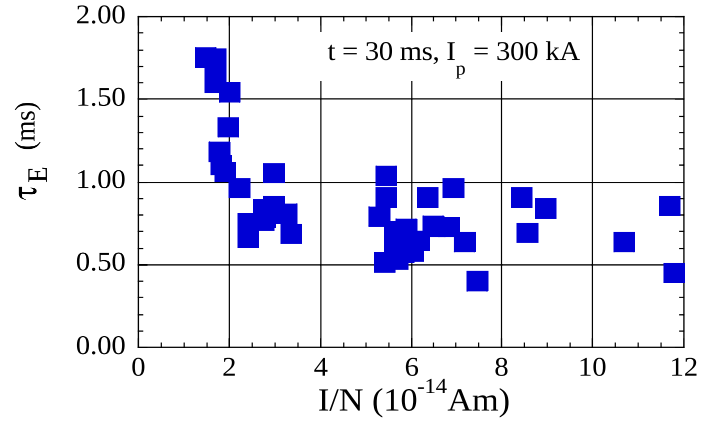

Figure 3(b) Energy confinement time versus I/N.

3. Radiation loss power

In order to know the direction in terms of the operating conditions to improve global confinement, it is of importance to investigate the power balance in the standard operating condition. We report here the first observation of the radiation power loss in TPE-RX by means of a set of bolometers. Five bolometers of a Gelmanium thermister type, which has a rise time of 10 μ sec, are installed on discrete ports of the TPE-RX. Data from a bolometer, which observes through a central chord away from the thick shell gap, is used here.

Figure 4(a) shows that the radiation fraction, P_{rad}/P_{oh}, versus *I/N* in the gas puffing experiment. It is shown that P_{rad}/P_{oh} is approximately 20% in the standard condition at I_p = 300 kA, while the fraction increases to 35% at the lowest *I/N* (~ 2 X 10^{-14} Am). This result confirms that the lowest *I/N* is limited by the radiation loss as is the case at the Greenwald limit in Tokamaks. On the other hand,

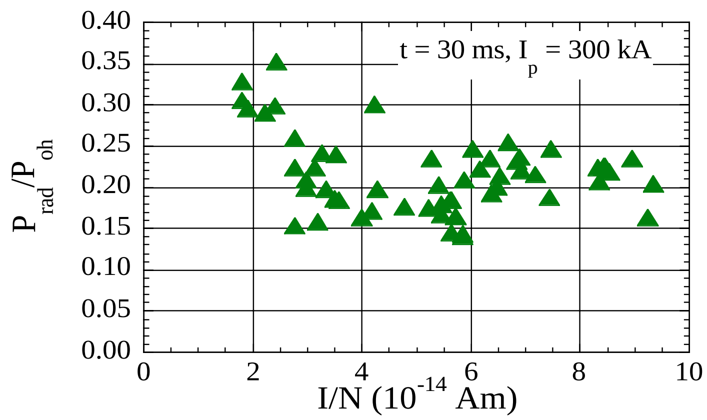

Figure 4(a) Radiation fraction versus I/N.

P_{rad}/n_{el} decreases when gas puffing is conducted, indicating the reduction of impurity density with n_e. On the other hand, P_{rad}/P_{oh} has a weak dependence on I_p (Fig. 4(b)). The fraction slightly increases at I_p > 350 kA to 20-25%. It should be noted here that the ohmic input power, P_{oh}, increases with I_p and it reaches to 17 MW at t = 30 ms of I_p = 400 kA.

4. Other operating regimes and summary

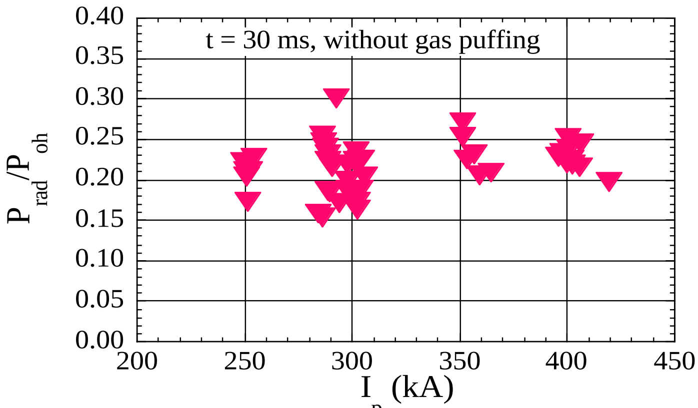

Figure 4(b) Radiation fraction versus I_p.

We have been trying several other operating regimes in order to improve global confinement. The Θ scan experiment has been conducted in order to realize the improved high Θ mode (IHTM) [5]. At the moment, Θ and *F* are not well maintained in time due to the lack of the energy in the toroidal reversal bank system. Under this limitation, improvement of β_p and τ_E with Θ is not yet clearly observed. An active control for the equilibrium position has been optimized by means of the DC vertical field and the pulsed vertical field for the initial cancellation of the vertical field to assist gas break down. The loop voltage decreases with a finite DC vertical. However, at the moment we need further optimization to enlarge the operating condition with the DC vertical field. Neon gas puffing is also tried, which might establish a radiation mantle and reduce total radiation loss. The result is reported in [7]. In summary, among all regimes we have tried for improvement, PPCD and gas puffing show improvement of the global confinement properties in TPE-RX. The highest β_p and τ_E in TPE-RX are 22% and 1.8 ms, respectively, both of which are obtained in the gas puffing experiment. This milestone point exceeds the level of the constant beta poloidal scaling database for the representative RFP plasmas [8]. We will further optimize the operating conditions and install additional power supplies, particularly to realize a multi-pulse PPCD and to enlarge the operating region with the DC vertical field.

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