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Existence and Parameter Dependence of the Locked Mode in TPE-RX

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1. Introduction

This paper reports the situation of the locked mode in the newly started, large RFP machine, TPE-RX (major/minor radii, R/a=1.72/0.45 m) at Electrotechnical Laboratory [1]. The locked mode might influence the global confinement properties by interacting with the wall of the vacuum vessel. Particularly, we review the typical characteristics of the locked mode in TPE-RX and present the dependence of the locked mode on the operating conditions. Among the experimental scans of the operating conditions, field error scan is intensively presented.

A large number of magnetic pickup coils for the radial magnetic field component have been installed on the TPE-RX. One group of the coils (RM-coils) which have 215 × 725 mm^2 × 10 turns and are placed at the top, bottom, inside and outside of the torus, is used for the measurement of the perturbed magnetic fields around the torus, and these signals give information of the locked mode phenomena. Another group of the coils (Br-coils) which have 60 × 60 mm^2 × 15 turns is used for the measurement of the local field error at poloidal thick shell gap.

2. Locked mode in TPE-RX

The phase- and wall-locked mode is found to exist in TPE-RX [2]. Overall characteristics are quite similar to those of the locked mode observed in RFX [3]. Figure 1 shows the last closed flux surface (LCFS) calculated from a data set of RM-coils in three dimensional space [2]. The actual shift is magnified by a factor of 30 in this plot. It can be seen from Fig. 1 that there are large shifts of the LCFS in a toroidally localized space. The toroidal distribution of

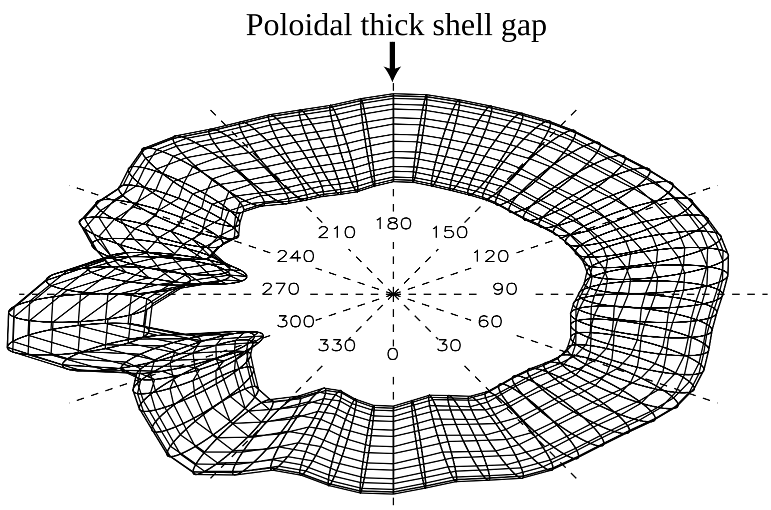

Figure 1: The last closed flux surface (LCFS) calculated from a data set of RM-coils.

m=0 and 1 mode have peaks at the locked position which corresponds to the place where the shift of the LCFS is largest. A clear correlation between the position of the maximum LCFS shift and the enhanced plasma wall interaction is observed. In this case of Fig. 1, the locked mode exists clearly at toroidally 280 degree. The locked mode persists from the current rising phase and the locked position remains over times throughout the discharge.

3. Operating condition dependence of the locked mode [2]

It is found that the locked mode disappears in certain experimental condition in TPE-RX while all the discharges show the locked mode in RFX. The results of the operating condition scanning show that the existence of the locked mode depends on the filling pressure of the fueling deuterium gas, p_{D2}, and the current rise time, τ_{Ip}, as shown in Fig. 2. Figure 2 (a) shows the result of the p_{D2} scan at I_p = 200 kA and τ_{Ip} = 20 ms. The probability of the locked mode increases as the p_{D2} increases at 0.4 < p_{D2} < 0.7 mTorr, and the locked mode exists in every discharge when p_{D2} is more than 0.7 mTorr. Figure 2 (b) shows the results of the current rise time scan at p_{D2} = 0.7 mTorr and I_p = 200 kA for τ_{Ip} < 37 ms or I_p = 100 kA for τ_{Ip} = 37 ms. The probability of the locked mode decreases as the τ_{Ip} decreases at τ_{Ip} > 20 ms. The locked mode dose not exists at τ_{Ip} = 37 ms. In the case of the I_p scan experiment in TPE-RX, it seems that I_p has a weak dependence on the existence of the locked mode. Next we investigate the correlation

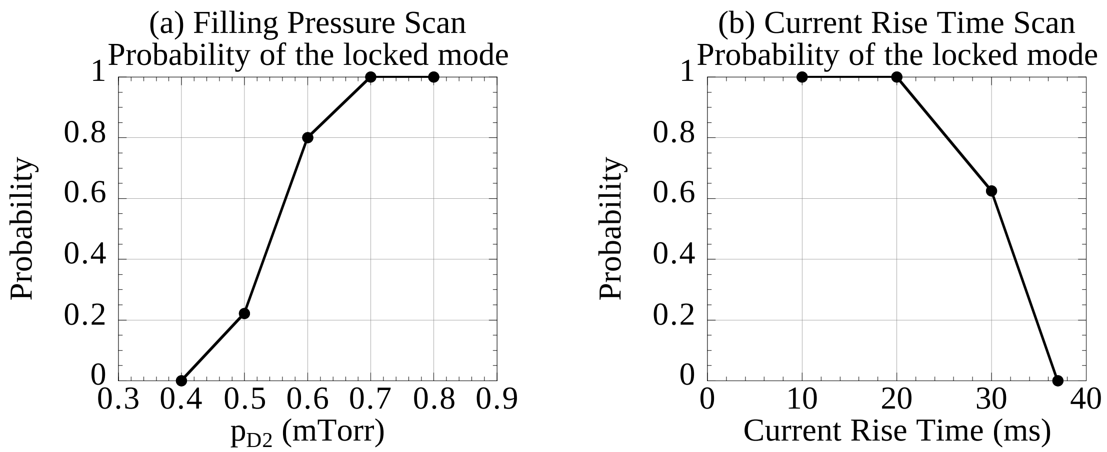

Figure 2: Dependence of the existence of the locked mode on (a) the filling pressure of the fueling deuterium gas p_{D2}, and (b) the current rise time τ_{Ip}.

between the strength of the field error and the locked position. An experiment using the saddle coil (SDC) system is conducted to scan the strength of the field error. Before presenting the results of the offset field error scanning, we briefly summarize the effect of the offset field error on the global confinement properties below.

4. Saddle coil (SDC) and offset field

The SDC produces the feed-back controlled local fields at the poloidal thick shell gap and is used for delicate cancellation of the field error. Figure 3 shows the poloidal distributions of the field error at the thick shell gap. The vertical component of the field error can be corrected by using the SDC as described by blank squares in Fig. 3. The blank circles show that the offset vertical field is produced at the thick shell gap using the SDC. In this case, the strength of the offset field is -0.013 Tesla and remains constant during the discharge. By using this technique, we artificially scan the field error at the shell gap to see the effect of the magnitude of the field error on the global properties (Fig. 4). The abscissa is the normalized field error $B_{error}/|B_p|$, where B_{error} is the field error measured by the Br-coil placed at the poloidal angle of 90 degrees (top of the poloidal cross section) at the thick shell gap for each shot in all of the graphs and B_p is the poloidal field produced by the plasma current I_p at the Br-coil position. We scanned the offset field as 0, +/- 0.013, +/- 0.0065 Tesla. The solid squares show the experimental results when the SDC is not used, and the blank squares show the experimental results when the feed-back control and offset field of the SDC are added. When the normalized field error $B_{error}/|B_p|$ exceeds 5%, the field error affects the global confinement properties. Within the shot to shot deviations, the experimental results without the SDC vary with the strength of the field error similarly to the case when the offset field is artificially added.

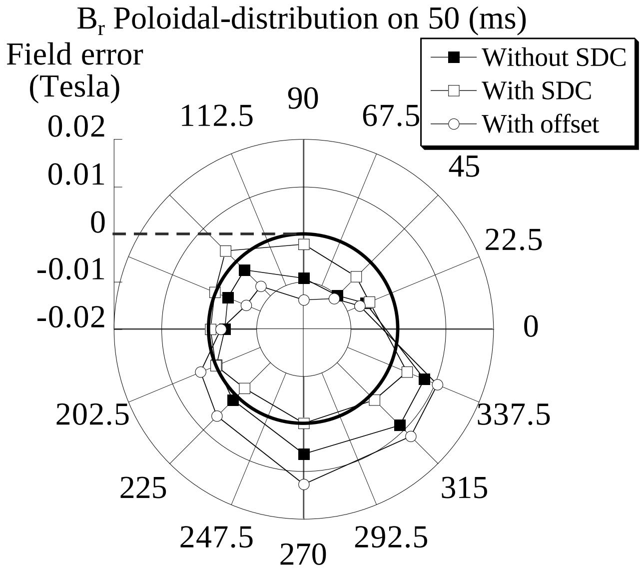

Figure 3: Poloidal distribution of the field error at the thick shell gap.

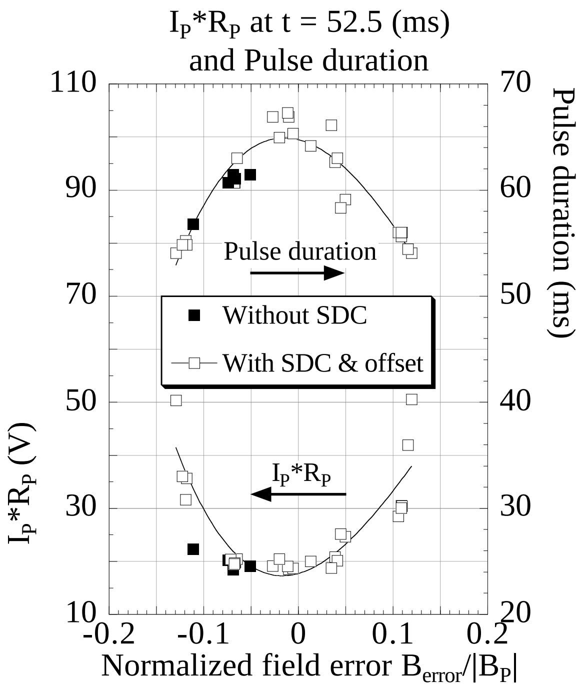

Figure 4: The pulse duration and the noninductive part of loop voltage R_p*I_p calculated from the modified Bessel function model plotted versus the normalized field error measured by a Br-coil.

5. Probability of the mode-locking at the source of the field error

As one of the experimental dependences, a correlation between the strength of the local field error and the locked position is obtained by scanning the offset field error at the thick shell gap. The offset field at the shell gap is scanned as, 0, +/- 0.013, +/- 0.0065, +/- 0.0033 Tesla, where the p_{D2} = 0.7 mTorr and I_p = 350 kA. In this condition, the locked mode exists in every discharge. Figure 5 shows the probability for the locked mode to occur within 22.5 degrees around the thick shell gap. The field error measured by the Br-coil normalized by B_p is chosen for the abscissa. In the case without the additional field error, the locked position differs shot-to-shot, and the probability of the locked mode to occur at the shell gap is less than 40 %. It is seen that as the field error increases, the mode tends to lock more frequently near 180 degrees. When the field error at the shell gap exceeds 8 % of B_p, the probability of the locked mode occurring at the shell gap increases twice as large as for the case without the additional field error. It is suggested that the locked position can be controlled by the local field error. This result is somewhat similar to what is reported in MST [4], where modes are normally phase-locked but not wall-locked, and they lock to the wall when the local field error exceeds ~ 5 %. More details of the effect of the field error are reported in Ref. [5].

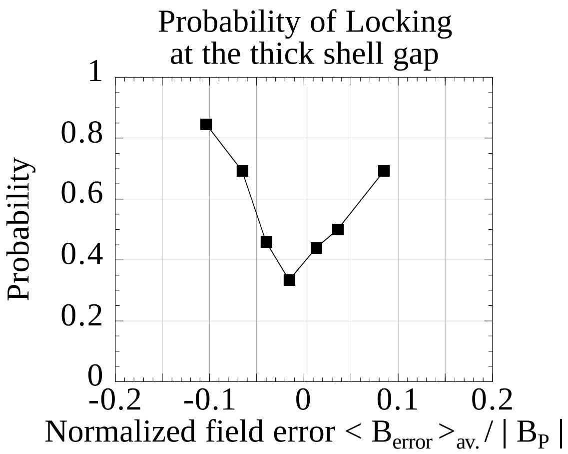

Figure 5: The probability for the locked mode to occur within 22.5 degrees around the thick shell gap.

6. Conclusions

When the field error exceeds 5% of the poloidal field, the field error affects the plasma parameter. Experimental scans of the operating conditions are systematically conducted, and the existence of the locked mode is found to depend on the filling pressure of the deuterium gas and the rising time of the plasma current. The probability of the locked mode to occur at the source of the field error increases as the field error increases and becomes more than 70% when the field error strength increases to more than 8% of the poloidal field. The locked position can be controlled when the source of the field error is sufficiently large.

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