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Comparison of the Behaviour of Reversed Field Pinch Plasmas with and without Locked Mode on TPE-RX.

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ABSTRACT

Discharges with and without the locked mode (the LM) are compared in the reversed field pinch experiment on TPE-RX. It is found that the wall locking of the m=1 modes can appear without the LM and the LM is brought about by the phase locking triggered by a rapid growth of core resonant m=1 modes, followed by the growth of other modes. The rapid growth of the mode is sensitive to the values of reversal and pinch parameters, which suggests the possibility that the growth of modes, hence the LM can be avoided by the careful control of reversed field. The LM can be eliminated by applying the rotating toroidal field, but the plasma is degraded by that field.

1. Introduction

It is observed in many reversed field pinch (RFP) experiments [1,2,3] that phases of several toroidal Fourier modes align to each other and form toroidally localised magnetic fluctuations (phase locking), which sometimes stays in a certain location of the torus (wall locking). (Hereafter we call it as the locked mode (the LM) which locks both in phase and wall.) The mechanism of the LM has been studied with the comparison of experimental and theoretical results in RFX and it is also demonstrated that the toroidal motion of the LM can be driven by applying the rotating toroidal field [4,5].

In TPE-RX, (a RFP machine, R/a = 1.72m /0.45m, plasma current Ip up to 480 kA and discharge duration slightly less than 0.1s) [6], it is possible to obtain discharges without the LM in certain conditions [3], such as in low filling pressure (p_0<0.5mTorr) and small plasma current (Ip<=250kA). The LM becomes more frequent as Ip and/or p_0 increase [3,7]. The Ip of 250kA is marginal, over which the LM appears in almost all cases even with the p_0 as low as possible. In some discharges with Ip equal to or smaller than 250kA, the LM takes place in the middle of the discharge near the current peak (t~35ms). In this report, comparison between discharges with and without the LM on TPE-RX will be presented in the almost same discharge conditions at Ip~250kA.

2. Comparison of the discharges with and without the LM

Typical example of the discharge with the LM which takes place at t~35ms is shown in Fig.1 and 2, which show time variations of m=1/n=6-9 mode amplitudes (Fig.1) and phase dispersion of m=1 modes at several time points for the fluctuation of toroidal field (δBt). The phase dispersion becomes zero when phases of all modes are completely locked [8]. After the setting up phase (<20ms) the δBt becomes very small between 20ms and 35ms. Then, at about t~35ms, the δBt suddenly increases nearly by a factor of five. This sudden increase is followed by occurrence of the LM. The sudden increase of the m=1 modes is rapid (<~1ms) and the dominant mode is mainly m=1/n=7, which is the core resonant mode with the lowest n value.

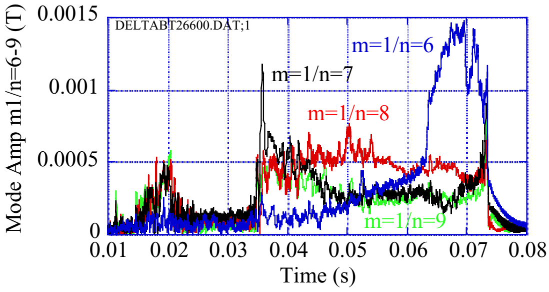

Fig.1
Amplitudes of m=1/n=6-9 fluctuation of the toroidal magnetic field in the discharge with the LM, which takes place at the middle of the discharge (t~35ms).

This growth of modes is very sensitive to the reversal and pinch parameters (F and Θ). Figure 3 shows the variation of m=1/n=6-9 modes in the discharge without the LM, which become possible with a little reduction of the reversal of toroidal field. The fluctuation level stays very low level during the almost whole discharge. The δBt is smaller by a factor of three than that in the LM cases. One very interesting thing is that the wall locking is observed even in this case. Phase of each mode exhibits very slow variation, although the phase locking and the LM do not take place.

Trajectories in the stability diagram on α–Θ_0 plane [9] exhibit clear difference. The LM case approaches to the unstable region for internal resonant ideal mode and then the rapid growth of an m=1/n=7 mode is observed. After it has grown, the growth of other resonant modes follows. Strong interaction of these modes with large amplitudes possibly results in the phase locking and finally the LM.

It is interesting to note that the wall locking has already begun before the rapid growth of the mode also in this case with the LM. The m=1 modes stop to rotate after the setting up (t~20ms), but the phase locking does not take place until the rapid growth of modes (t~35ms). This fact, together with the fact that the wall locking is observed even in the case without the LM, suggests the possibility that the LM can be avoided by avoiding the phase locking, which is triggered by the growth of resonant modes, with the proper choice of the path in the α-Θ_0 plane by the careful control of the reversed field.

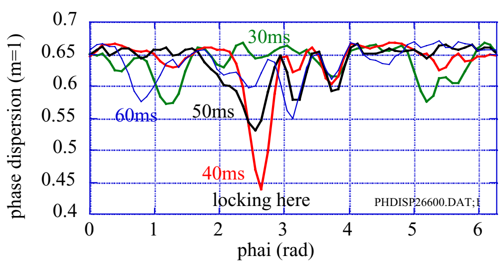

Fig.2
Phase dispersion at t=30ms, 40ms, 50ms and 60ms in the discharge with the LM, which takes place at t~35ms.

In addition it is observed that the effect of the LM on plasma performance becomes evident after t~35ms. As shown in Fig.4, the resistive part of toroidal loop voltage (RpIp) increases from 20V to 23V and the rapid decay of soft x-ray emission is observed.

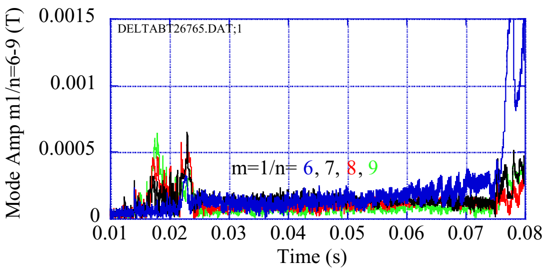

FIg.3
Amplitudes of m=1/n=6-9 fluctuation of the toroidal magnetic field in the discharge without the LM during the almost whole discharge.

3. Control of the LM with the rotating toroidal field (RTF)

In order to control the LM, a similar method as used in RFX [5] has been introduced in TPE-RX. The RTF is produced by an auxiliary toroidal field system, which consists of 16 additional auxiliary toroidal field coils and 16 independent power supplies. In the typical condition (5ms pulse width, 9.6ms rotation period), the maximum local toroidal field about 10mT is produced and the main rotating component (m=0/n=1) is 2-3 mT.

This RTF is applied to the discharges in which the LM takes place at t~35ms (Fig.1 case). The RTF starts at t=30ms. Two rotating periods, 4.8ms and 9.6ms are examined. In both cases, unlocking of the phase in both m=0 and m=1 modes is observed as shown in Fig.5, where only a little indication of the phase locking is observed after t>30ms. Variation of the phase of each mode is quite strange and the rotation of the LM is not clearly observed. The m=0/n=1 mode, and possibly m=0/n=2 mode are rotating, but m=0/n>2 modes exhibit only slow movement slightly affected by the RTF. Phases of dominant m=1 modes only show very slow variation which almost independent to the RTF. The amplitudes of m=1 modes become a little smaller than those in the usual discharges with the LM. These facts indicate that the RTF affects mainly on the phase locking, may not on the wall locking of m=1 modes and is effective to eliminate the localisation of fluctuation.

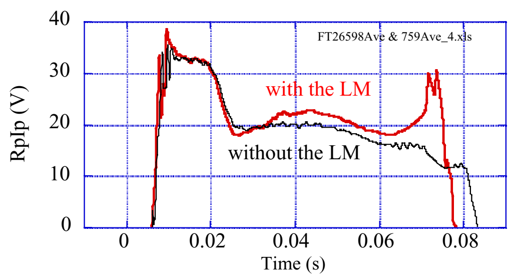

Fig.4
Comparison of resistive part of toroidal loop voltage with and without the LM.

Effect of the RTF on the plasma cannot be neglected. The reduction of soft x-ray signal and increase of RpIp values are clearly observed when the m=0/n=1 component of the RTF exceeds 1mT, which is slightly smaller than the necessary level to control the LM.

4. Conclusion

Discharges without the LM is possible in the low current region (Ip=<250kA) of RFP experiments on TPE-RX, hence, the discharges with and without the LM can be compared in the same plasma current (Ip~250kA). The δBt without the LM can be kept in very small level.

There is a case where the LM takes place in the middle of the discharge at Ip ~ 250kA. Examining this discharge, it is found that the wall locking of the m=1 modes has already taken place before the LM takes place, and the LM is brought about by the phase locking, which is triggered by a rapid growth of core resonant mode followed by the growth of other m=1 and 0 modes.

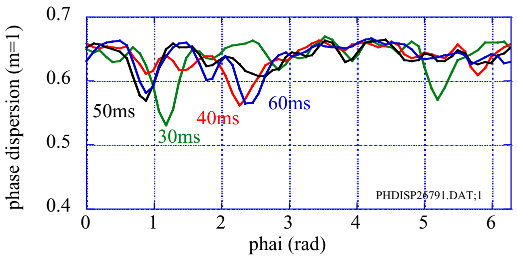

Fig.5
Phase dispersion at t=30ms, 40ms, 50ms and 60ms in the discharge with the RTF. Phase locking does not take after t>30ms.

The LM can be eliminated by applying the RTF with m=0/n=1 component. The wall locking of m=1 modes is not affected by the RTF but the phase locking can be avoided because of the rotation of m=0/n=1 component. In TPE-RX, the plasma is degraded by the RTF with the amplitude slightly smaller than that necessary for controlling the LM.

It is interesting to point out that the quasi-single helical state with m=1/n=6 is observed near the termination of discharges (see Fig.1), where the F and Θ values become shallow and small. Probably that mode is the core resonant mode with the smallest n for those values of F and Θ. However, the reason why only this mode grows so large is not clear.

Acknowledgement

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