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Resistive tearing modes dynamics with plasma control in a reversed field pinch

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Introduction

Different operating scenarios have been tested in recent years to improve the overall plasma performance of reversed field pinches: quasi-single helicity (QSH), pulsed poloidal current drive (PPCD) and active feedback stabilization (AFS). In particular, in the EXTRAP T2R reversed field pinch, QSH and AFS, AFS and PPCD [1] techniques have been tested simultaneously showing encouraging results. A preliminary study with selective AFS in EXTRAP T2R has been carried out, leaving the (m, n) = (1, -12) internally resonant resistive Tearing Mode (TM) un-controlled, as a way of triggering QSH as an exploratory experiment on active control of the QSH. In this work we present the results of two experiments aimed to further develop improved operation scenarios: (i) use of PPCD in selective AFS discharges, and (ii) PPCD aided by pulsed toroidal voltage.

Experimental set-up

The reference plasma scenario is characterized by deep reversal (F = -0.45): for this equilibrium the TM (m, n) = (1, -12) is marginally resonant. In this reference plasma, the AFS is used in the targeted-mode closed-loop control with proportional control gain $K_p^{m,n}$ = 20 for (m, n) = (1, $-16 \leq n \leq 15$) thereby suppressing the radial component at the wall radius of both RWMs and TMs. In an attempt to induce QSH on a specific TM, selective AFS is used by setting $K_p^{m,n}$ = 0 for the selected TM: in the first set of discharges m = 1 and n is either -12, -13 or -14. In such plasma, a single PPCD with an edge poloidal electric field of 1.5 Vm^{-1} is then applied during the growth phase of the untargeted TM. A second set of similar discharges has been performed in which $K_p^{m,n}$ = 0 for all the TMs. The reference plasma scenario for the aided PPCD is characterized by normal reversal (F = -0.23) with or without FB. On this reference, a capacitor bank is discharged into the poloidal field coils during the flat top slightly before the application of PPCD. The dynamic of the TMs and of the RWM is monitored using a radial (2 × 32) and a poloidal (2 × 64) set of magnetic field coil sensors.

Experimental observations

The response of the plasma to selective AFS in which the most internally resonant mode (m, n) = (1, -12) is left uncontrolled is very strong: radial component of this mode grows throughout the discharge as shown in panel (a) of figure 1, ultimately leading to the wall-locking of the TMs and to the discharge termination. However, in such a discharge QSH with dominant mode other than the uncontrolled one do occur [2]. This is also true when selective feedback is used to induce QSH with dominant mode other than (m, n) = (1, -12): a typical example is shown in figure 2 where QSH with dominant mode (m, n) = (1, -12) is observed when $K_p^{1,-13} = 0$. When PPCD is applied, the plasma response is typical of PPCD discharges: reduction of the TMs amplitude, increase of the SXR signal, reduction of the resistive loop voltage and sustained rotation as it can be seen in figure 1. It is interesting to observe that the temporary change in equilibrium caused by PPCD is reflected in a change in the growth rate of the uncontrolled tearing mode.

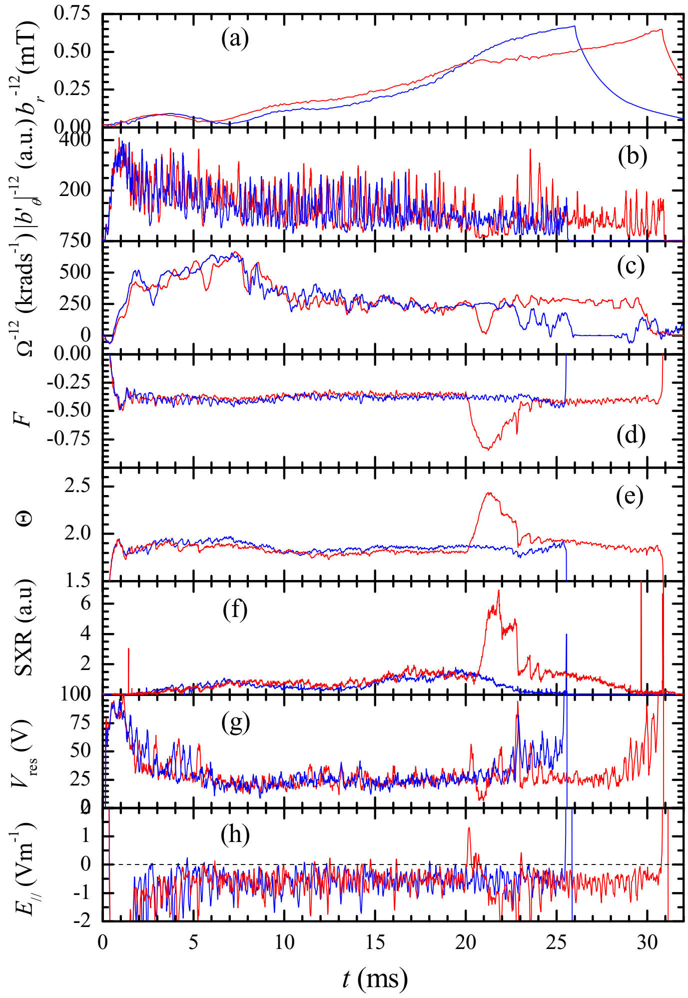

Figure 1. Time evolution of the global parameters for discharges with selective AFS only (blue, #20892) and with the addition of PPCD (red, #20900). From top to bottom: (a) radial component of TM n = -12, (b) poloidal component of TM n = -12, (c) helical phase velocity (d) reversal parameter, (e) pinch parameter, (f) SXR, (g) resistive loop voltage and (h) parallel electric field.

Some of the discharges with selective feedback, with one or more uncontrolled TMs, exhibit an unexpected behaviour as shown in figure 3: with $K_p^{1,-12} = 0$, the amplitude of the un-integrated signal associated to the poloidal field component of TM (m, n) = (1, -12) is larger than the amplitude of all the other TMs for very long times and it is characterized by a fast variations in time. The helical phase velocity of this mode is much larger then that of the other TMs.

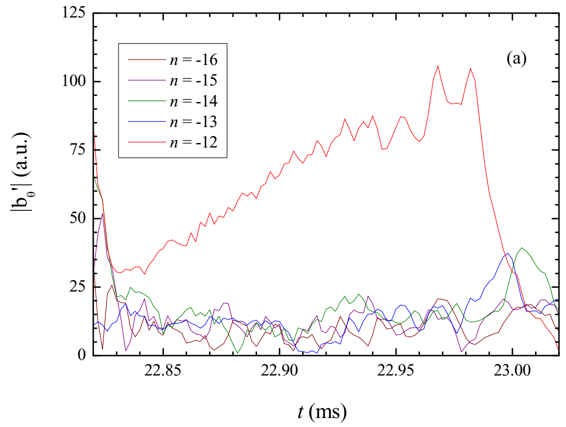

Figure 2. Examples of QSH with dominant mode n = -12 during selective AFS for mode n = -13 (#20891).

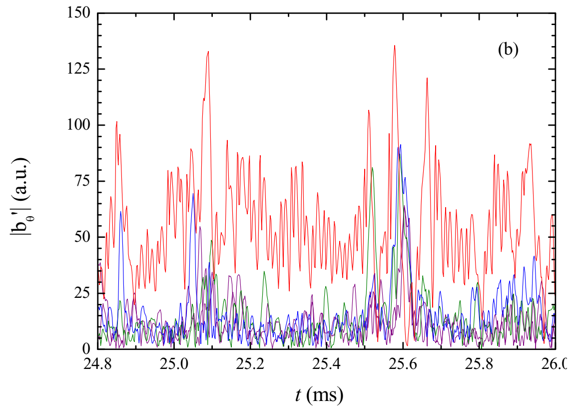

Figure3. Selective AFS for mode n = -12 exhibiting a QSH-like behaviour (#20906).

This behaviour is very different to the spontaneous QSH states observed in EXTRAP T2R [3] both for its duration and time evolution. In all the discharges with selective AFS on a single mode analysed in this work, no QSH has been observed during PPCD. The first observation of QSH also during PPCD has been made when $K_p^{m,n}$ = 0 for all the TMs with $-16 \leq n \leq -12$ as shown in figure 4. In this case, the QSH occurs with two different dominant modes only during the increase of the SXR signal. As observed, selective feedback stabilization in which $K_p^{m,n}$ is set to zero for a specific TM does not result only into QSH states of the corresponding dominant mode. However, removing feedback control to all the TMs has provided the first evidence of QSH during PPCD in EXTRAP T2R. These preliminary observations point to the fact that, during PPCD, QSH states can be more easily induced if the TMs are not completely suppressed: a more sophisticate technique is therefore required to allow a fine tuning of partial feedback suppression (that is, $0 < K_p^{m,n} \leq 20$) of each individual mode, the reason possibly being that QSH states emerge by non-linear interaction of the TMs and therefore a certain level of fluctuations is required before the QSH state formation.

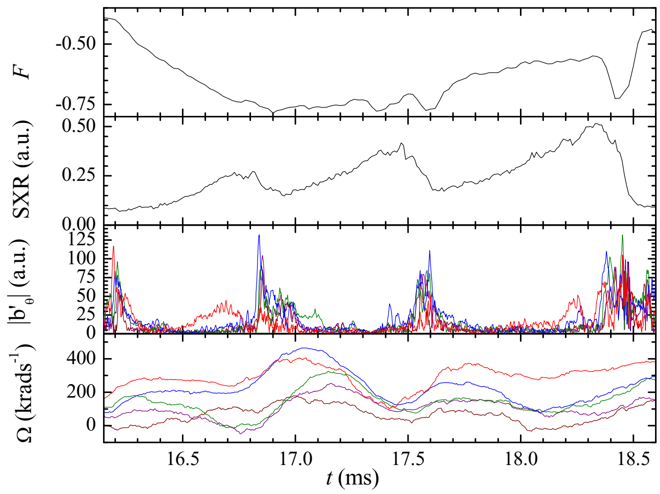

Figure 4. QSH with n = -12 and -14 during PPCD and with AFS excluded for TM modes n = -16 to -12.

Aided PPCD has been successfully tested for the first time in EXTRAP T2R with and without AFS, the latter case being shown in figure 5. The most striking effects are, beyond the obvious increase in the plasma current, the huge ten-fold increase in the SXR signal, much larger than any increase observed by PPCD alone, and a three-fold increase in the electron density: the two are obviously connected since the SXR signal typically scale with the square of the electron density. Temperature measurements with a Thomson scattering system are at present still inconclusive but the observation that the helical phase velocity of the TMs increases during the aided PPCD is an indication that the electron temperature is also positively affected. The SXR signal is also characterized by a smoother growth on top of which SXR crashes are observed without however causing the SXR signal to drop to pre PPCD level as often occurs in standard PPCDs. The resistive loop voltage is not however decreasing possibly due to the cancelling effect of the increased loop voltage when the additional ohmic bank is applied. Finally, it is interesting to observe that during the aided PPCD the H_α signal is not changing significantly apart for some spikes associated with SXR crashes thus indicating that the observed increase in the electron density is not due to an increased plasma wall interaction. During aided PPCD, short QSHs (less than 0.2 ms) were observed with dominant modes (m, n) = (1, -12) and (1, -13) with spectral number Ns < 2 [4]. Similar results to the ones described above are also obtained when aided PPCD is applied to discharge with AFS in the intelligent shell scheme.

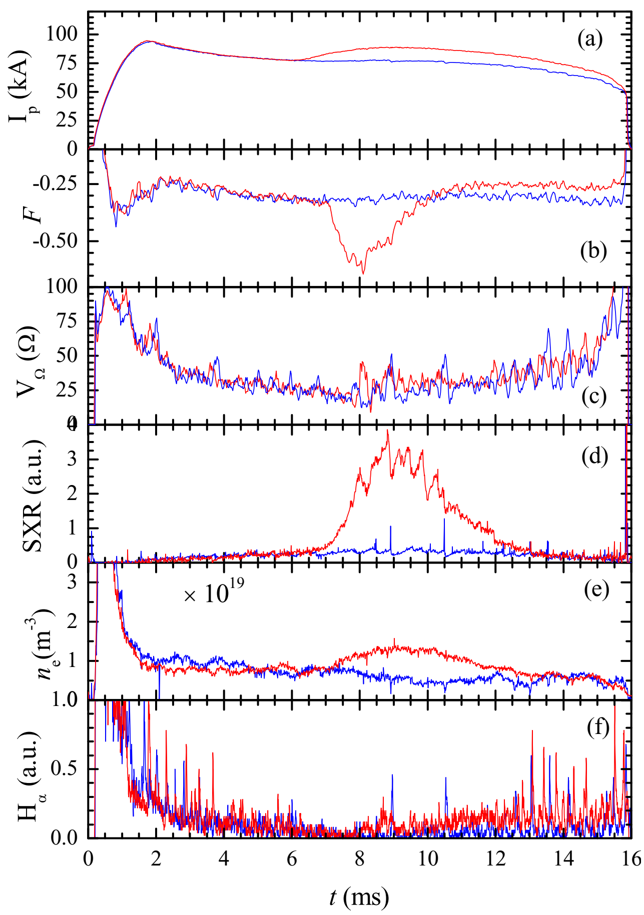

Figure 5. Reference discharge (blue, #20989) and aided PPCD without FB (red, #20993): reference (a) plasma current, (b) reversal parameter, (c) resistive loop voltage, (d) SXR signal, (e) electron density and (f) H_α signal.

References

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[3] L Frassinetti *et al* 2007 *Phys. Plasmas* 14 112510

[4] Y L Ho *et al* 1995 *Phys. Plasmas* 2 3407