

# A multi-machine study of the interaction between locked modes and plasma rotation

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## 1 Introduction

In tokamaks, tearing modes, a class of magneto-hydro-dynamic instabilities, can interact with the passive structures, inducing eddy currents which slow down the plasma rotation. When the rotation velocity is reduced to a critical value, the magnetic island associated to the mode locks and grows up to large amplitudes, leading often to a disruption [1].

A reduced plasma flow also implies the loss of the beneficial roles of plasma rotation, such as the reduction or suppression of both MHD [2] and turbulent [3] instabilities.

Locked modes (LMs) can also be induced by applying magnetic field perturbations (MPs).

The objectives of this work are (1) to investigate the rotation braking caused by the presence of a LM [4] and (2) to assess the role of the plasma density in the evolution of the rotation profile, through the analysis of JET, MAST-U and ASDEX Upgrade datasets.

## 2 Experimental Methodology

In JET and in AUG, LMs have been triggered when applying  $n = 1$  MPs, during error field identification experiments in the Ohmic plasma regime. This external perturbation has been

induced by means of the Error Field Correction Coils (EFCCs) in JET [5] and the B-coils in AUG [6]. The rotation has been inferred through the Charge Exchange Recombination Spectroscopy (CXRS), by applying short NBI blips.

On the other side, in MAST-U, a database with  $n = 2$  externally applied MPs has been analyzed. These perturbations have been applied through the Edge Localized Mode (ELM) coils, in experiments aimed at studying the mitigation / suppression of ELMs [7]. The plasma regime is in H mode and the South South (SS) NBI injector provided the CXRS measurements.

The LM amplitude has been calculated by analyzing signals from the saddle coils, which are located externally to the vacuum vessel.

### 3 Analysis and Results

In JET and in AUG, CXRS measurements have been taken while keeping the density constant and ramping up the current in the EFCCs and in the B-coils, respectively.

In Figure 1, the analysis of JET shots is presented. Panel (a) shows the rotation braking in the plasma core, when the external perturbation is increased, consistently with [4]. Panel (b) represents the edge rotation, which slightly increases because of the LM onset.

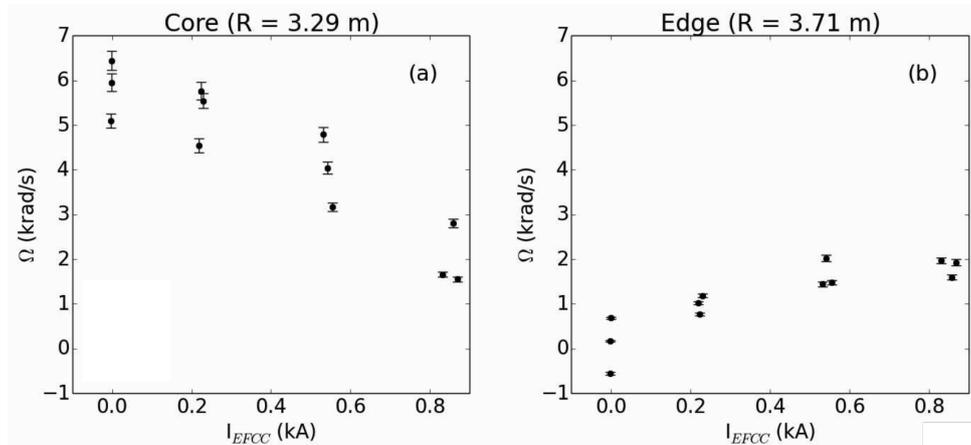


Figure 1: Toroidal rotation measurements in the core (a) and at the plasma edge (b) as a function of the EFCC current in JET.

In Figure 2, similar results are reported for AUG. Note that, in this case, the core rotation braking occurs in the counter-current direction and the edge rotation tends to decrease as the B-coils current is increased.

In MAST-U, when a  $n = 2$  MP has been applied, CXRS measurements have been taken while the plasma density evolved. Figure 3 shows the rotation braking in the core, which is consistent with the previous observations in JET and in AUG.

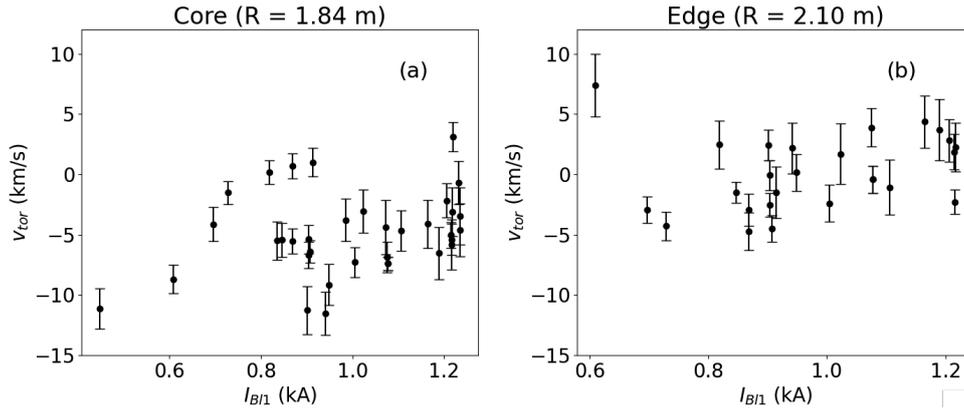


Figure 2: Toroidal rotation measurements in the core (a) and at the plasma edge (b) as a function of the B-coils current in AUG.

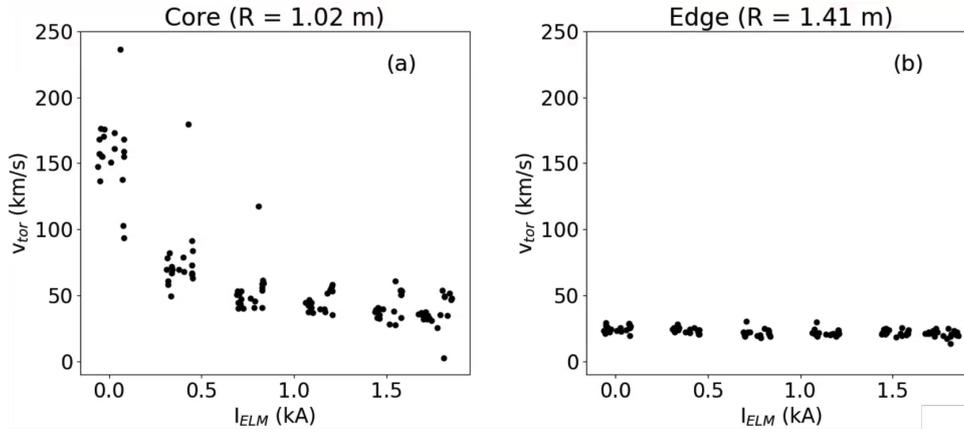


Figure 3: Toroidal rotation measurements in the core (a) and at the plasma edge (b) as a function of the ELM coils current in MAST-U.

The rotation braking, consistently observed in AUG, JET and in MAST-U, can be associated with the presence of the electro-magnetic, the viscous and the neoclassical toroidal viscous torques. The role of these terms in the momentum balance equation will be investigated through modeling.

For JET and AUG databases, in the same shots CXRS data has been taken when no LM was present and the plasma density was varied. Previous works in JET [9] and in AUG [8] reported that, starting in a low plasma density regime, the core rotation profile experiences a peaked-to-hollow (first) transition, while increasing the density, and it comes back to a peaked profile (second transition), when the density is further increased. As documented in [8], this phenomenon can be associated to a residual stress mechanism, which arises when the normalized logarithmic gradient of the plasma density changes. In Figure 4, panel (b) depicts the second transition in JET, whereas panels (d, f) show respectively the first and the second transitions in AUG. Note that the density regimes in which the two transitions occur are machine-dependent.

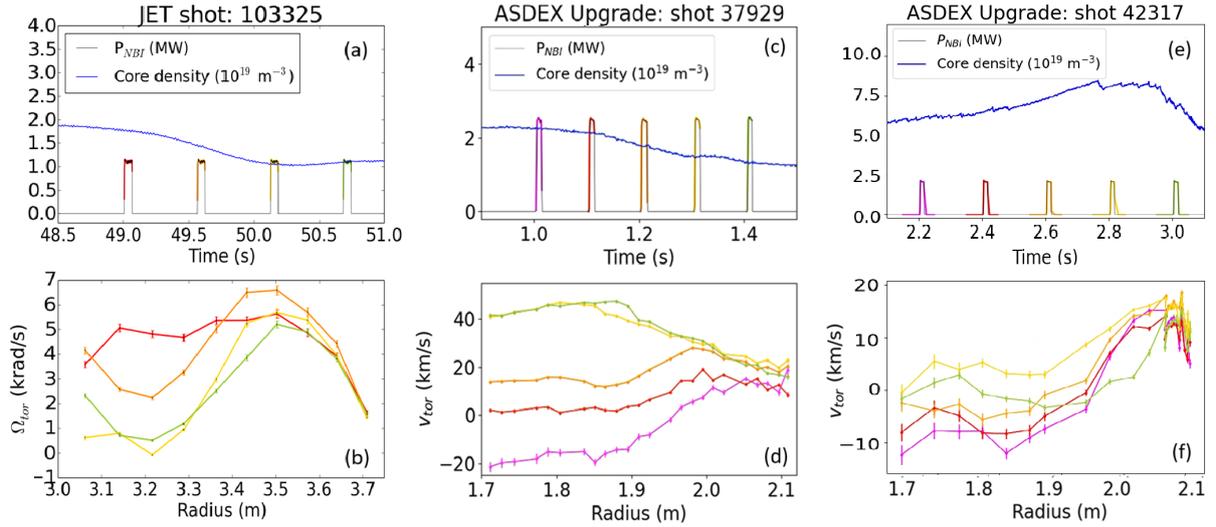


Figure 4: (b) Second core profile transition in JET and (d) first and (f) second profile transition in AUG, during CXRS measurements taken while varying the plasma density (a, c, e) in the absence of LMs.

## 4 Conclusions

A multi-machine database has been collected, including shots realized in JET, AUG and MAST-U, aiming at highlight in the three devices the mechanisms involved in the interplay between plasma rotation and locked modes. The study allowed to observe (1) the plasma rotation braking caused by externally applied 3-D magnetic fields and (2) the role of a changing plasma density in the core rotation profile evolution, in the absence of external perturbations. The experimental analysis will be validated through a model which solves the momentum balance equation.

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