Island healing in stellarators: the cases of LHD and TJ-II

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Introduction

Magnetic islands have a strong influence on plasma confinement (see [1] and references therein): islands can modulate transport, degrading or reducing it, and can give rise to strong instabilities like NTMs and interchange modes in tokamaks [2]. Beyond their influence on confinement, islands are proposed as a divertor system in stellarators when they are located in the edge. The research on island dynamics is hence basic, making mandatory to identify in which conditions the dynamics changes from growth to healing.

According to the modified Rutherford equation, there are several ingredients that have influence on the island dynamics provoking a transition between growth and healing: magnetic shear, variable electric field (through ion polarization current) or, equivalently, variable poloidal flow, and pressure gradient. The influence of electric field has also been investigated in [3], showing that its influence is not negligible. The modified Rutherford equation can be written as (see e. g. [2]) :

$$\frac{dW}{dt} = \frac{r_s}{\tau_r}\left(r_s\Delta' + \Delta_{bootstrap} + \Delta_{polarization} + \Delta^{\Lambda} + ...\right) \qquad (1)$$

Previous works have shown the influence of $\Delta_{bootstrap}$ through ∇p in TJ-II [4], while the effect of influence of poloidal flow, given by E×B, is explored in this work both in LHD and TJ-II during the evolution of the magnetic island, showing that the poloidal flow starts increasing before the magnetic island transits from growth to healing, and vice-versa. The increment of the poloidal flow prior to the magnetic island transition from growth to healing is observed, indicating that the poloidal flow modification affects the magnetic island dynamics. The poloidal flow appears through the polarization current term, $\Delta_{polarization}$, and through the effect on ion-electron fluxes unbalance term, Δ^{Λ}, and also modifies the bootrap current, thus having influence on $\Delta_{bootstrap}$.

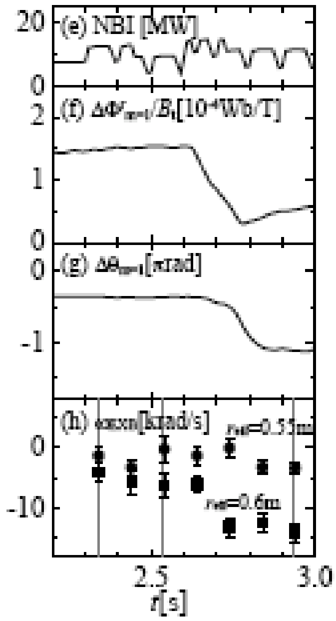

Figure 1

The LHD case

LHD experiments have shown pressure and collisionality (β and ν) ranges in which the island is healed in the quasi-steady state [5], but the reason for this healing is still open. In this device a seed island with poloidal/toroidal Fourier mode numbers are m/n=1/1. The resonant surface of ι/2π = 1 lies at reff = 0.55 m. The experiments that vary the NB injected power and the resonant field amplitude ($\Delta\Phi^{r}_{m=1}/B_t$), can be used to clarify the dynamic behavior of the magnetic island when it passes from growing to healing, the heating power of the neutral beam (NB) has been changed in a single discharge. It is observed experimentally that the poloidal flow starts increasing before the magnetic island transits from growth to healing regime, and vice versa. The island is detected clearly by a flattening of the electron temperature (T_e) measured near the O-point. The profiles of poloidal flow ($\omega_{E\times B}$) are also measured near the X-point of the island in intervals of 0.1 s (the toroidal angle of the measurement position is different from that of T_e), thus having a time evolution of such a quantity. The time evolution of NB power, resonant field amplitude ($\Delta\Phi^{r}_{m=1}/B_t$), difference of the poloidal angle of X-point from the seed island ($\Delta\theta_{m=1}$) and $\omega_{E\times B}$ at reff = 0.55 m (circles) and 0.6 m (squares) is shown in Fig. 1 (e-h). The magnetic island dynamics is as follows: $|\omega_{E\times B}|$ at reff = 0.6 m (Fig.1(h)) increases from t = 2.34 s to 2.54 s prior to the island being healed; $\Delta\Phi^{r}_{m=1}/B_t$ starts decreasing at t = 2.62 s which means that the island width decreases (see Fig.1 (f)). At that time, $|\omega_{E\times B}|$ at reff = 0.6 m further increases from 6 to 13 krad/s. The poloidal angle $\Delta\theta_{m=1}$ is shifted to the electron-diamagnetic direction at t = 2.67 s (see Fig.1 (g)), which implies that the current sheet in the plasma is modified by the poloidal flow. Simultaneously, $|\omega_{E\times B}|$ at reff = 0.55 m (around ι/2π = 1) increases from ~0 to 3.2 krad/s between t = 2.74 and 2.84 s.

The TJ-II case

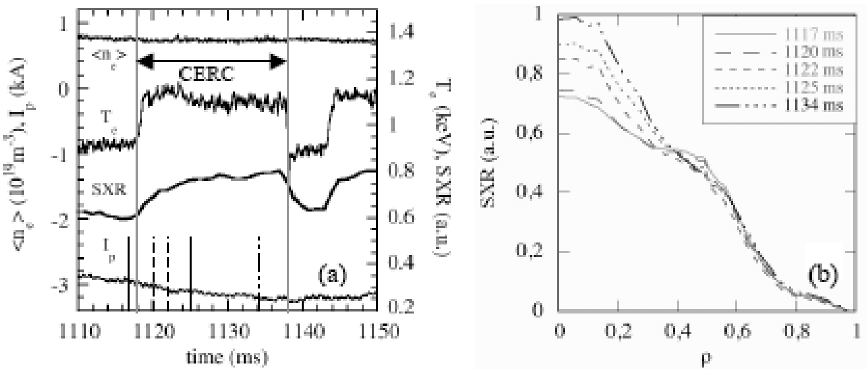

Figure 2

TJ-II experiments [6] show a similar behavior of the island dynamics despite the different parameter range. Here the island with m/n = 2/4 is introduced in the plasma by using OH current. The unbalance between electron and ion fluxes causes the onset of a strong positive radial electric field, E_r, which triggers the transition to the so called core electron-root confinement (CERC). Figure 2(left) shows the density, central Te, SXR emission and Ip evolution. It is seen that the jump of Te coincides with the CERC onset and it gives information of the radial electric field evolution, since the shape of the electrostatic potential is similar to the Te one [7]. The SXR profile evolution is plotted in Figure 2(right) showing how the flattening disappears and the island is healed: island healing follows the CERC established at t = 1118 ms. Before the CERC onset, the local flattening of soft X-ray profiles at ρ = 0.4 appears at t = 1117ms, which shows the existence of a magnetic island. The island lasts until t = 1120ms just after the CERC formation. After that, the magnetic island disappears at t > 1122ms. These experimental observations show that $\omega_{E\times B}$ changes prior to the island dynamics, as was seen in LHD.

Discussion

From these experimental data it is clear that the relevant quantity is $|\omega_{E\times B}|$ rather than $\omega_{E\times B}$. The electric field influences several terms of equation (1) as has been sated above. Beyond the

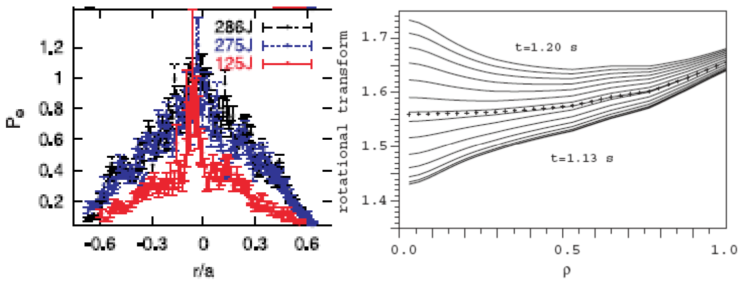

Figure 3. Left: pressure profiles masured by Thomson Scattering in TJ-II for negative shear (black and blue) and for positive shear (red). Right: Estimated rotational transform profile during these measurements. The red case shows clearly the flattening due to the presence of a rational with positive low shear.

effect of the electric field it is also necessary to consider other important factors that are playing a role in the island dynamics, like the bootstrap current, which has a clear impact on island healing in the stellarator core during CERC formation. The main difference between the island dynamics in tokamaks and stellarators is caused by the different rotational transform $\iota/2\pi$ (the inverse of the safety factor q) profiles of those two devices: while $\iota/2\pi$ decreases with minor radius in tokamaks, it increases in stellarators, thus producing a stabilizing effect and tending to heal the islands when the current is opposite to the magnetic field. The presence of a non-zero shear (although it can be very small) is also a key ingredient for island healing. TJ-II experiments have shown that the island strongly grows when positive shear is created by inducing a positive current [8] by the OH coils as can be seen in Figure 3.

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