*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, O-4.028 (2008)*

Nonlinear Dynamics of Magnetic Islands Imbedded in Plasma Microturbulence

M. Muraglia[1,2], O. Agullo[1,2], S. Benkadda[1,2], X. Garbet[3], P. Beyer[1,2]

[1] *France Japan Magnetic Fusion Laboratory, Marseille, France*

[2] *LPIIM, CNRS Université de Provence, Marseille, France*

[3] *IRFM, Association EURATOM CEA, CEA Cadarache, France*

In a tokamak, plasma confinement can be strongly affected by MHD activity. More precisely, the tearing instability allows a breakup and a reconnection of the magnetic field lines along current-flow lines and finally a macrocospic magnetic island can appear. However, in a magnetized confined plasma, magnetic islands can coexist with small scale turbulence and zonal flows. Actually, the opposition of a pressure gradient with the curvature leads to an interchange instability. This situation leads to the production of a small scale turbulence and zonal fows. Although several works were devoted to the study of tearing [1] and interchange [2]instabilities separately, only few investigations were devoted to explore the mutual interaction between these instabilities. For example, several experiments report the coexistence of both microturbulence and MHD activities showing some correlated effects. More precisely, microturbulence is observed in Large Helical Device plasmas [3] and MHD activities are observed in reversed shear plasmas with transport barriers related to zonal flows and microturbulence [4].

In this work, we study the interaction between a tearing mode and a pressure gradient instability (interchange like instability). Some numerical and theoretical studies of linear and nonlinear drift tearing mode behaviour have been done for the limit cases where the pressure effect is to trigger mainly the interchange instability and does not play any fundamental role in the *nature* of the tearing mode [5], [6], [7]. However, as we will show, it exists regimes where the amplitude of the equilibrium pressure gradient controls, linearly and nonlinearly, the nature of the process of the magnetic equilibria. As a main effect, this can lead to a competition of tearing and interchange structures. The competion of the two instabilities affects strongly the dynamics : small scales are produced and a nonlinear poloidal rotation of the island appears.

A Reduced MagnetoHydroDynamic based model, where interchange and tearing instability mechanisms are present, is adopted [8]. Typically, it involves a set of coupled equations for the electrostatic potential ϕ, the pressure of the electrons P and the magnetic flux ψ. We suppose that the magnetic field is dominated by a constant component along the z-direction. The time evolution of the three fields can be described by :

$$\partial_t \nabla_\perp^2 \phi + \left[\phi, \nabla_\perp^2 \phi\right] = \left[\psi, \nabla_\perp^2 \psi\right] - \kappa_1 \partial_y P + \nu \nabla_\perp^4 \phi, \tag{1}$$

$$\partial_t P + [\phi, P] = -V_d \left((1-\kappa_2)\, \partial_y \phi + \kappa_2 \partial_y P\right) + C^2 \left[\psi, \nabla_\perp^2 \psi\right] + \chi_\perp \nabla_\perp^2 P, \tag{2}$$

$$\partial_t \psi + [\phi - P, \psi] = -V_d \partial_y \psi + \eta \nabla_\perp^2 \psi, \tag{3}$$

where $V_d = \frac{2\Omega_i \tau_A L_p}{\beta L_\perp}$. The sum of the electron and ion momentum balance equations leads to the plasma motion equation Eq. (1) where ν is the viscosity. Eq. (2) comes from the energy conservation and $\chi_\perp$ is the diffusivity. Then Eq. (3) is the Ohm's law with η the resistivity. $\beta = \frac{P_0}{B^2/2\mu_0}$ is the ratio between pressure and magnetic energies, L_p is the pressure gradient length, $L_\perp$ is a macroscopic length related to the island width, R_0 is the major plasma radius, $\Omega_i = \frac{eB}{m_i}$ is the ion cyclotronic frequency and τ_a is the Alvèn time. Equations (1), (2), (3) are normalized using the characteristic Alfvèn speed $v_A = B_0/\mu_0 n m_i = L_\perp/\tau_a$.

κ_i parameters are linked to the curvature and to the pressure gradient ($\kappa_1 = 2\Omega_i \tau_A \frac{L_\perp}{R_0}$ and $\kappa_2 = \frac{10L_p}{3R_0}$), so these parameters control the interchange instability. In the other hand, in Eq. (2), tearing mode is controlled by the coupling parameter $C = \frac{5T_e}{3L_\perp^2 \Omega_i^2 m_i}$. More precisely, this parameter allows the coupling between the pressure and the magnetic flux. The nature of the linear and nonlinear dynamics of the magnetic island will depends strongly of the intensity of the coupling. This model takes into account both tearing modes and electromagnetic interchange for the limit case where the electronic temperature is constant and the ion are cold. The cold ion limit can be assumed because we expect that the ion temperature does not affect strongly the stability of the tearing mode. Moreover, the parallel ion dynamic is not included in the energy balance equation Eq. (2).

To characterize how small scale turbulence affects the evolution of a magnetic island, linear and nonlinear self consistent numerical simulations using semi spectral codes are performed. The grid number is $n_x = 128$ for the radial direction and $n_y = 64$ for the poloidal direction. The box sizes are the same in the two directions : $L_x = L_y = 2\pi$. For simplicity, a focus on the interaction of basic mechanisms is done. In particular, the linear diamagnetic effect is suppressed, some interchange modes are unstable ($\kappa_1 = 10^{-2}$, $\kappa_2 = 0$) and a strong coupling between the pressure and the magnetic flux is chosen ($C = 1$).

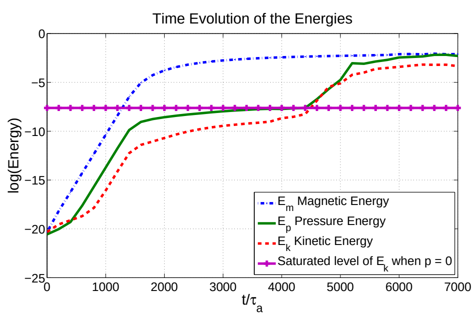

Figure 1: Time Evolution of the Energies

Figure (1) shows the time evolution of the magnetic, pressure and kinetic energies for the case where $\nu = \chi_\perp = \eta = 10^{-4}$. So four regimes are observed. First, a linear regime where the magnetic island is formed. Second, the system reaches a quasi-plateau phase characterized by a slow growth of the energies. We can note that, from an energy point of view, in these regimes, magnetic flux and pressure both dominate, the kinetic energy being to weak to let the flow holds up the island. Actually, a strong coupling between the pressure and the magnetic flux is chosen $C = 1$. And, as a result, the growth of the magnetic island is controlled by an interplay between the pressure and the magnetic flux. More precisely, the magnetic island is kept by pressure cells which compress the current sheet. In these two regimes, the electrostatic potential does not play any fundamental role in the dynamics, however, the kinetic energy increases gradually. At the end of the second regime, the flow has enough energy to let the interchange process occurs. Indeed, on the figure (2), snapshots of the electrostatic potential ϕ, the pressure P and the magnetic flux ψ, during the third regime, are presented. Outside the magnetic island, the pressure and the flow balance mutually : interchange cells are generated. However, the magnetic island is still maintained by pressure cells inside the island. We can also observe that, on the pressure snapshot, the interchange structure (outside the island) is in competition with the tearing structure (inside the island). This competition leads to a strong generation of small scales which participate at the dynamics. Finally the two structures are not compatible and a transition occurs. This is around $t \sim 5100\tau_A$ in the figure (1) where an abrupt growth of the kinetic and pressure

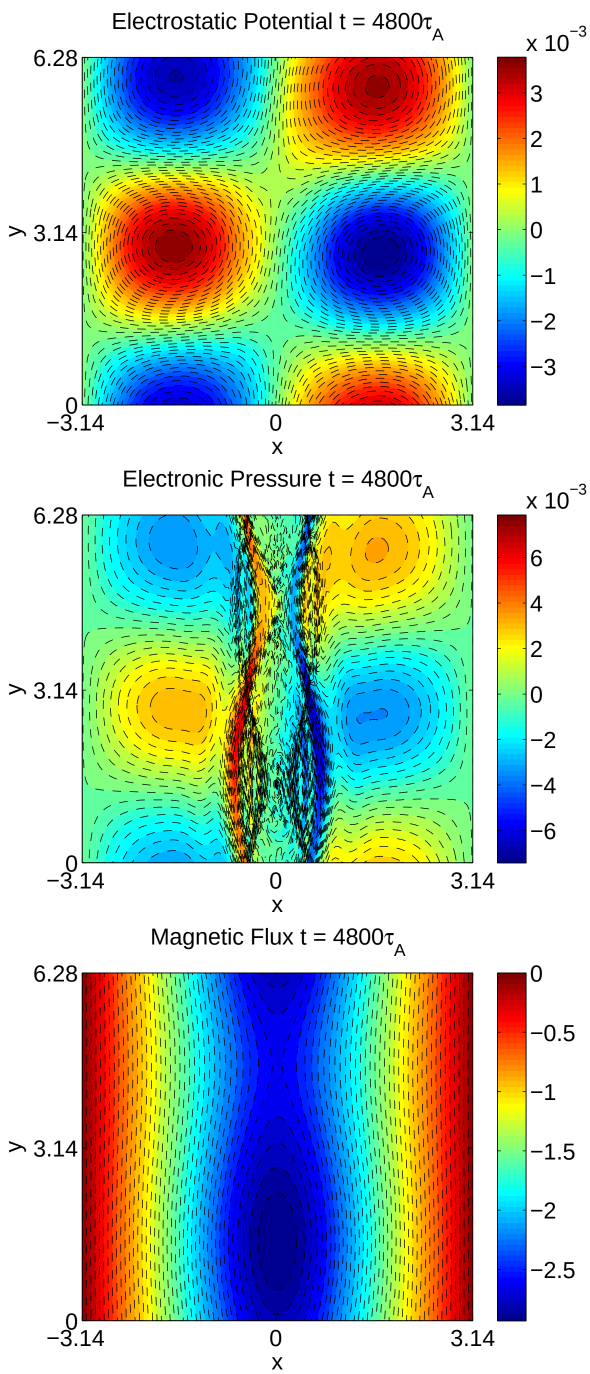

Figure 2: Snapshot of the fields

energies occurs. The dynamical system finally adopts a new behaviour, and a pressure island appears inside the magnetic island. In the latter phase, a mean flow is generated by small scales and an island poloidal rotation is triggered.

In conclusion, interchange instability affects strongly the linear and nonlinear dynamics of the magnetic island. For a strong coupling between the pressure and the magnetic flux, the nature of the formation of the magnetic island is affected by the pressure effects : the magnetic island is driven and is kept by the interplay between the pressure and the magnetic flux. Nonlinearly, there is a competition between interchange and tearing structures. As a result, small scales are strongly generated and a bifurcation occurs. Finally the system reaches a new dynamics characterized by a concentration of the pressure inside the magnetic island.

References

[1] P. H. Rutherford, Phys. Fluids **16**, 1903 (1973)

[2] S. Benkadda, X. Garbet and A. Verga, Contrib. Plasma Phys. **34**, 247 (1994)

[3] K. Tanaka *et al.*, Nucl. Fusion **46**, 110 (2005)

[4] S. Takaji *et al.*, Nucl. Fusion **42**, 634 (2002)

[5] F. Militello, F. L. Waelbroeck, R. Fitzpatrick and W. Horton, Phys. Plasmas **15**, 050701 (2008)

[6] C. J. McDevitt and P. H. Diamond, Phys. Plasmas **13**, 032302 (2006)

[7] A. Furuya, S.-I. Itoh and M. Yagi, J. Phys. Soc. Japan **70**, 407 (2001)

[8] R. D. Hazeltine, M. Kotschenreuther and P. J. Morrison, Phys. of Fluids **28**, 2466 (1985)