Nonlinear simulations of core density collapses in Large Helical Device

[1]J. VARELA, [2]Y. TAKEMURA, [2]K.Y. WATANABE, [1]B. BREIZMAN, [1]F.WAELBROECK, [3]D. SPONG (3), [4]L. GARCIA, [3]Y. GHAI and [1]D. DEL-CASTILLO-NEGRETE

[1]Institute for Fusion Studies, Department of Physics, University of Texas at Austin, Austin, Texas 78712, USA
[2]National Institute for Fusion Science, National Institute of Natural Science, Toki, 509-5292, Japan
[3]Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-8071, USA
[4]Universidad Carlos III de Madrid, 28911 Leganes, Madrid, Spain

Email: jacobo.rodriguez@austin.utexas.edu

1. SYNOPSIS

The motivation of the present study is simulating the CDC event to gain a better understanding of how instabilities located in the plasma periphery can induce the plasma collapse at the core, an analysis relevant to the design of future stellarator reactors with low magnetic shear and resonant rational surface of high toroidal mode families at the plasma periphery. Towards that goal, linear and nonlinear simulations are performed using an updated version of the FAR3d code; this includes the parallel magnetic field perturbation by imposing a radial balance between the magnetic and plasma pressure and neglecting the magnetic field bending effect [4,5]. Linear simulations, fig. 1, shows the destabilization of ballooning modes by the toroidal mode families above n=17 at the plasma periphery, around r/a = 0.7, radial location consistent to the experiment.

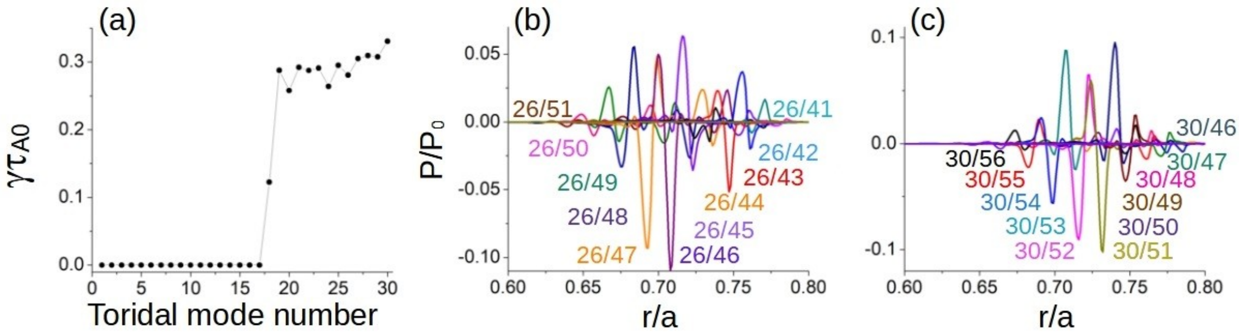

Fig 1. (a) Ballooning modes growth rate. Pressure eigenfunction of (b) n=26 and (c) n=30 perturbations.

Fig 2 shows a perturbation at the outer plasma (from t = $2400t_{A0}$) with amplitude increasing through the simulation. From t = $2480t_{A0}$, the perturbation at the outer plasma propagates towards the plasma periphery, and middle plasma region. The amplitude of the perturbation covering r/a = 0.4 to 1.0 further increases until the inner plasma is destabilized at t = $2560t_{A0}$. Four simulation phases are observed:
-Phase I: t = 2400 – $2480t_{A0}$, High n ballooning mode destabilization.
Phase II: t = 2480 – $2560t_{A0}$, High n ballooning mode saturation and inverse energy cascade to middle and low n modes. Low n modes are n=1 - 10, middle n modes n=11 - 20 and high n modes n=21 - 30.
-Phase III: t = 2560 – $2600t_{A0}$, inner plasma unstable and low n mode destabilization.
-CDC-like event: t > $2600t_{A0}$, low n modes induce a partial collapse of the pressure profile.
Inwards perturbation propagation and time scale of the simulation, 0.45 ms, consistent with the experiment.

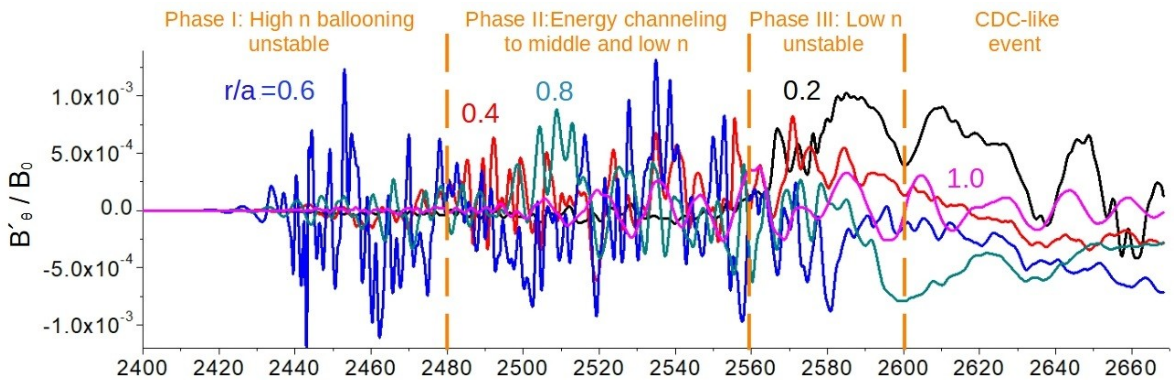

Fig 2. Evolution of the poloidal magnetic field perturbation through the simulation at r/a=0.2 (black), 0.4 (red), 0.6 (blue), 0.8 (cyan) and 1.0 (pink). Dashed vertical orange lines indicate different simulation phases.

Fig 3, panels a to d, show an energy inverse cascade from the saturating high n ballooning modes towards middle and low n modes, leading to the destabilization of the 1/1 mode in the CDC phase. Panel e indicates an m=1 perturbation nearby the magnetic axis. Panel f and g show the stochastization of the magnetic surfaces in the inner plasma by the m=1 perturbation leading to a partial collapse of the pressure gradient.

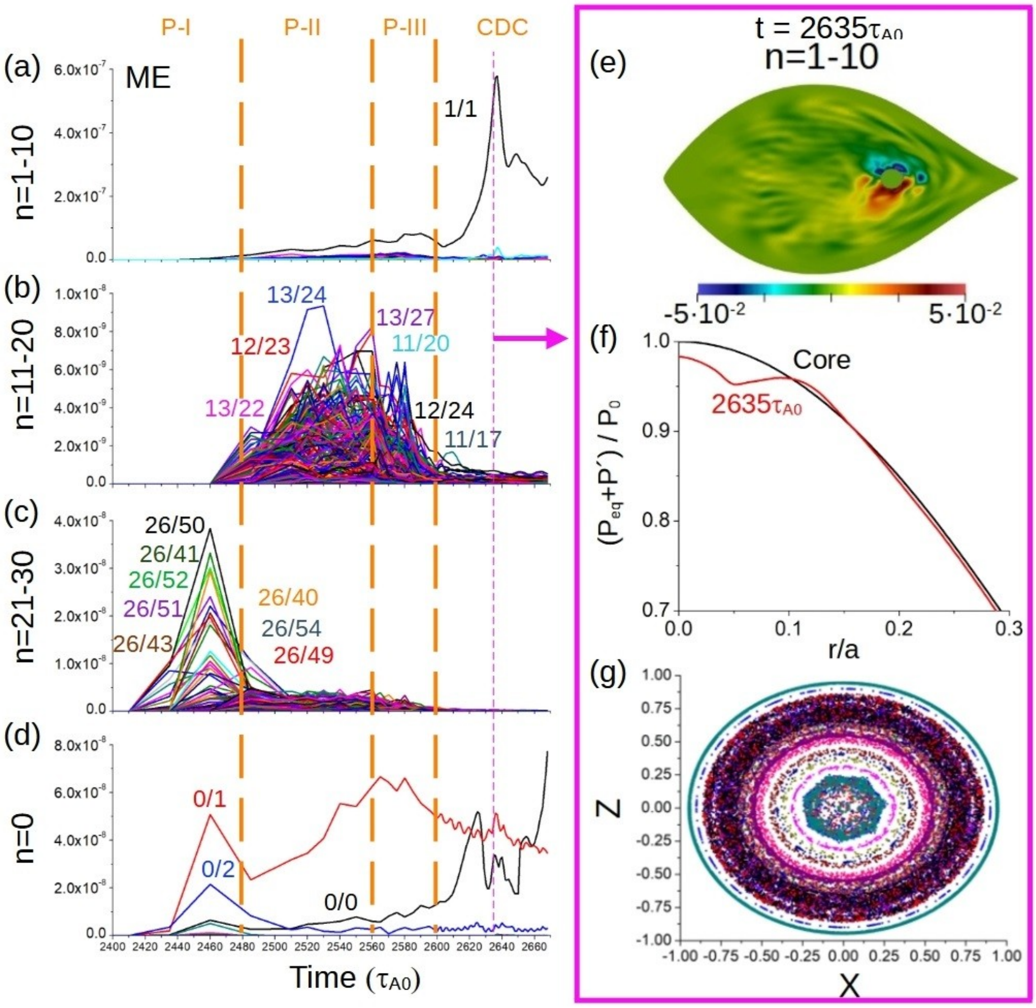

Fig 3. Magnetic energy evolution of (a) n=1-10, (b) n=11-20, (c) n=21-30 and (d) n=0. (e) Poloidal contour of the pressure perturbation for n=1-10. (f) Magnetic field Poincare plot. (g) Pressure profile evolution.

Summarizing, the simulations reproduce several features of the CDC observed in the experiments, particularly the perturbation inward propagation from the plasma periphery towards the plasma core. The plasma pressure collapse in the inner plasma may be caused by the stochastization of the magnetic surfaces induced by the m=1 perturbation at the plasma core, triggered by the inverse energy cascade from the saturating ballooning modes towards low n modes. The simulations also indicate the important role of the parallel magnetic field perturbation in the destabilization of the ballooning modes.

ACKNOWLEDGEMENTS

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