EUROFUSION WPSA-PR(16) 15461

L Pigatto et al.

Resistive Wall Mode physics in JT-60SA high beta$_N scenarios$

Preprint of Paper to be submitted for publication in
43rd European Physical Society Conference on Plasma
Physics (EPS)

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Resistive Wall Mode Stability in JT-60SA High β_N Scenarios

L. Pigatto[1], T. Bolzonella[1], J. Garcia[2], S. C. Guo[1], Y.Q. Liu[3], X. Xu[1]

[1]*Consorzio RFX, Corso Stati Uniti, 4 35127, Padova, Italy*

[2]*CEA,I IRFM, 13108 Saint-Paul-lez-Durance, France*

[3]*CCFE, Culham Science Centre, Abingdon OX14 3DB, UK*

Introduction The superconducting tokamak JT-60SA is being built in Naka (Japan) and has an important supporting mission for the development of fusion energy: designed to achieve long pulses (100 s) and break-even equivalent plasmas, it will help in both the exploitation of ITER and in solving key issues for the future DEMO devices [1]. JT-60SA will be able to explore plasma configurations with shape factor up to $S=q_{95}I_p/(aB_\varphi)$ ~ 7 (where B_φ is the toroidal field, I_p the plasma current in MA, a is the minor radius, q_{95} the safety factor at 95% of the toroidal flux) and aspect ratio down to A ~ 2.5. Additional heating and current drive systems will provide up to 41 MW for 100s, divided between 34 MW neutral beam injection and 7 MW of ECRF. The off-axis Negative-NBI at 0.5 MeV beam energy in particular, allows current profile tailoring for Advanced Tokamak scenarios with fully non-inductive current drive. In the present work the focus is set on high β_N scenarios, in which one or more Resistive Wall Modes (n=1, 2, 3) are potentially unstable. RWM instabilities are ideal MHD pressure driven modes (also called external kinks due to the caused plasma deformation) that develop when the normalized kinetic to magnetic pressure exceeds the so-called no-wall limit: $\beta_N = \%\beta * \frac{a\,B_\phi}{I_p} > \beta_{nw}$. A series of stability studies has been carried out with the 2D MHD codes MARS-F/K [2][3] focusing on the most unstable n=1 RWM. A plasma representative of reference Scenario 5.1 (high β_N, full CD, Single Null) is considered. The specific equilibrium has been obtained with 17 MW of NBI and 7 MW of ECRH heating, allowing for a good fraction of external power to be used for control purposes, with I_p = 2.3 MA and β_N = 3.6. The present work shows some initial steps into the assessment of the stability properties of this scenario, starting from the ideal kink stability limits. The Resistive Wall Mode instability is then considered from both the fluid and kinetic [4] point of view.

No-wall and Ideal-wall Limits

The original equilibrium has been smoothed in its internal profiles ($\frac{dp}{d\psi}$ and $T\frac{dT}{d\psi}$ where p is the pressure and T the poloidal current flux function) and plasma boundary, in order to avoid numerical issues and increase the resolution at the x-point. The resulting plasma boundary and q-profiles are shown in Fig. 1, it is worth noting that the smoothing procedure gives negligible changes in the original equilibrium. As a first step in understanding the stability properties of the aforementioned equilibrium the no-wall and ideal-wall β limits have been assessed with a pressure scan. The results predicting β_{nw} = 2.04 and β_{iw} = 5.80 (Fig. 2) are consistent with

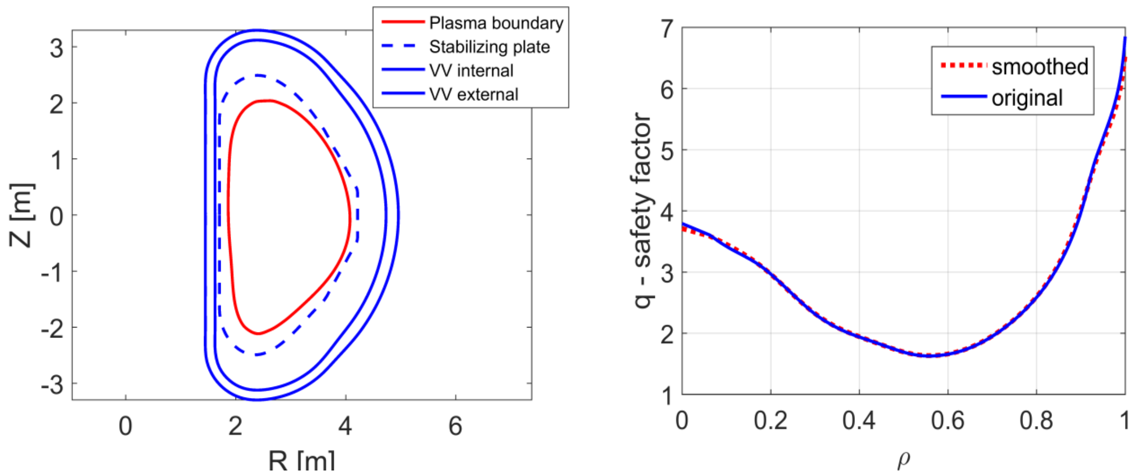

Figure 2 – *(Left) Plasma boundary, first wall (stabilizing plate) and vacuum vessel contours. (Right) Safety factor profile before (blue) and after (red dashed) smoothing of plasma boundary and internal profiles.*

those obtained for similar equilibria [5]. It should be stressed that only one wall has been implemented in this study (dashed in Fig.1 right plot), as a continuous 2D contour that does not take into account the real geometrical characteristics of the stabilizing plate such as gaps or non-uniformities. The plasma-ideal-wall distance has been scanned and set as to allow consistency with previous results. This however leads to an optimistic ideal wall limit; comparison with fully 3D simulations is foreseen in order to establish an equivalent effective wall position and obtain more realistic β_{iw} estimation. With a β_N = 3.6 the reference equilibrium is in between the calculated limits, in the so-called wall stabilized region, where the ideal wall stabilizes the external kink. Since any realistic wall has a finite resistivity this mode is not fully stabilized but slowed down from Alfvénic time scale to the wall penetration characteristic time. Being therefore called Resistive Wall Mode, this instability can be

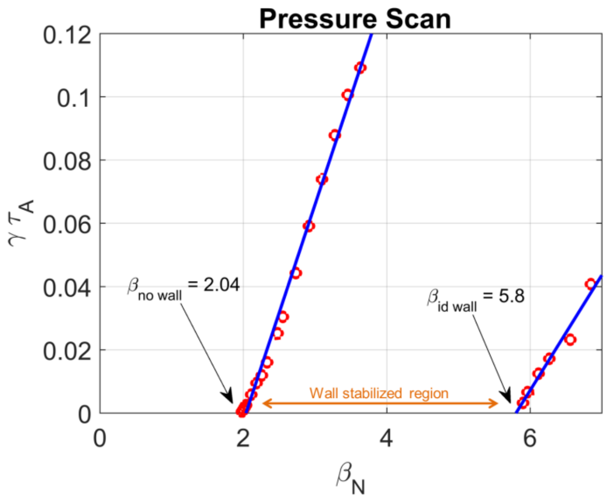

Figure 1 - *No-wall and Ideal-wall stability limits calculated with constant plasma current and ideal wall position b/a = 1.119*

influenced by both plasma flow and kinetic properties of the plasma. These relationships and their effect on mode dynamics are investigated in the following sections.

Fluid Rotation with Uniform and Parabolic Profiles

Stabilization of the most unstable n=1 RWM is explored with plasma rotation, an ion acoustic Landau damping term is included in the momentum equation, in particular as a viscous term. The perturbed viscous force can be expressed as: $-\nabla\vec{\Pi} = \rho\kappa_{\|}|k_{\|}v_{th,i}|\vec{v}_{\|}$ .This term is scaled with a coefficient $\kappa_{\|}$ which has been set to 1.5 in the present work. While the NBI systems on JT-60SA allow great flexibility in the design of plasma flow profiles, two simple cases have been considered for a discussion as general as possible. A parabolic rotation profile has been assumed and compared with the uniform rotation case. The effect of viscous damping on the RWM can be seen in Fig. 3 where the rotation at the innermost q=2 magnetic surface is scaled. A strong damping of the growth rate ($\gamma\tau_A$) is given by the uniform rotation profile in particular.

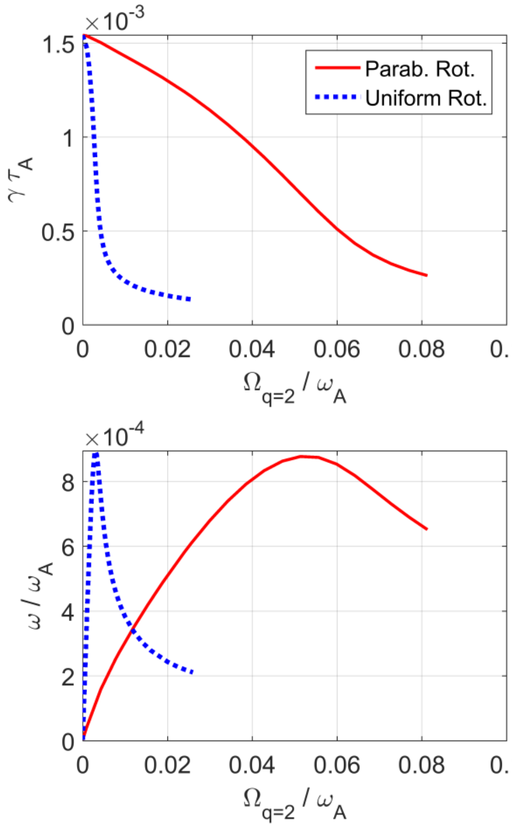

Figure 3 - *Eigenvalue scaling with toroidal plasma flow for uniform (dashed blue) and parabolic (red) rotation profiles. (Top) Real part, (Bottom) imaginary part.*

Kinetic contribution to RWM stability

Since the behavior of RWMs will also be influenced by kinetic effects [6] from both thermal and energetic particle populations from NBIs, these contributions have been included in the stability analysis. Thermal ions and electrons have been introduced as a first step, assuming a simple Maxwellian distribution and focusing on the resonance between the mode and the precession motion of trapped particles banana orbits. Energetic Particles (EPs) from normal NBI injection have been then introduced. For EPs a slowing-down distribution is assumed in particle energy space and isotropic distribution in particle pitch-angle [7]. For both cases the kinetic contribution to the pressure tensor is scaled though the α_D parameter, as shown in Fig. 4. The eigenvalue evolution with kinetic contribution is reported for both the two particle species and three particle species (including EPs) case. Detailed contributions to the mode perturbed energy are calculated as well. The effect of rotation is being assessed in presence of kinetic effects with the same

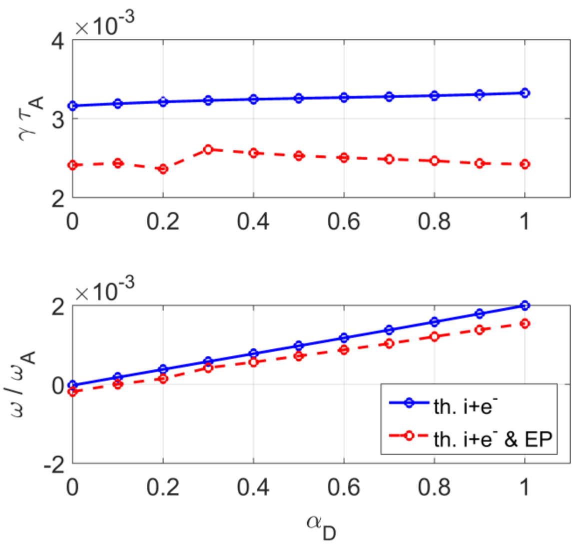

Figure 4 – *Eigenvalue evolution with scaling of kinetic effects with two populations (thermal ions and electrons, blue solid line) and three populations of particles (thermal ions and electrons + energetic particles, red dashed line). The parameter α_D represents scaling from fluid description (α_D=0) to full kinetic contribution to the pressure tensor (α_D=1).*

procedure followed in the purely fluid case, using a smaller parallel viscosity coefficient this time ($\kappa_{\|}$=0.1).

Conclusions and Outlook The ideal and no-wall β limits have been calculated for the n=1 ideal kink in the fully non-inductive scenario 5.1, future comparison with 3D calculations will allow a more detailed description and the effective 2D wall will be positioned. The n=1 RWM will be unstable in the scenario under investigation with a close-fitting resistive wall. Stability studies with fluid rotation have been carried out by implementing two simple profiles, none of which provides full mode stabilization. This means that the RWM cannot be stabilized by fluid effects only, kinetic contributions must be taken into account. The uniform rotation case in particular is found to give a stronger damping. An extended fluid analysis of the problem is possible with different, detailed rotation profiles and a 3D description of passive structures which would allow including new energy dissipation terms. Further physics is being implemented in the description step by step, starting with the kinetic contribution of thermal and EPs. Future work will consider more advanced distribution models for the latter. Mode evolution in both these cases is still under investigation but giving promising results when energetic particles are included in particular, though full stabilization has not been found. Active stabilization studies, which could prove to be necessary, are foreseen following two directions. A simplified physical description to be coupled with detailed 3D external structures on one hand, and a full kinetic description of the plasma with simplified 2D passive and active structures.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

[1] KAMADA, Y., et al, 2011, Nucl. Fusion 51, 073011
[2] LIU, Y., et al, 2000, Physics of Plasmas 7(9), pp. 3681-3690
[3] LIU, Y., et al, 2008, Physics of Plasmas, 15(11), 112503
[4] LIU, Y., et al, 2010, Nucl. Fusion 50, 095008
[5] XU, X., 2015, Ph.D. thesis
[6] HU, B., et al, 2005, Physics of Plasmas, 12, 057301
[7] LIU, Y., et al, Plasma Phys. Controlled Fusion, 52, 104002 (2010)