Interaction of energetic particles from neutral beam injection with Alfvén Eigenmodes in JT-60SA

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I – Introduction

The JT-60SA device offers unique conditions before ITER for the study of the interaction of energetic particles with plasma waves. With its JET similar dimensions e.g. major radius and slightly more elongated plasma volume, JT-60SA is a high power device with additional heating up to 41MW of (including 10MW of 500keV Neutral Beam Injection) and high non inductive plasma current operation. With such a significant energetic particle population (fast ion beta slightly below 1%), it is of utmost importance to predict the influence of these populations on the plasma stability since a net energy transfer from the energetic population to marginally stable plasma waves can potentially lead to an outwards radial transport of the hot ions. In this work, we investigate the drive/damping contributions from the Neutral Beam Injection (NBI) driven fast ions on Magnetohydrodynamic Alfvén Eigenmodes using the CASTOR-K code [1].

II – Plasma scenario and distribution functions

The planned operational scenario of JT-60SA addressed here ("Scenario3") is a full current inductive and high density scenario characterized by a plasma current of 5.48MA, toroidal magnetic field of 2.05T, 9.89/10.9x$10^{19}$$m^{-3}$ ion and electron densities on axis, ~5.94keV of ion and electron temperatures on axis and very low shear q~1 safety factor in the core. The plasma equilibrium is shown in Figure 1, evidencing the poloidal flux map (left), the plasma pressure, diamagnetic flux function (*F_dia*) and safety factor profiles (right) in radial coordinate S (square root of normalized poloidal flux)

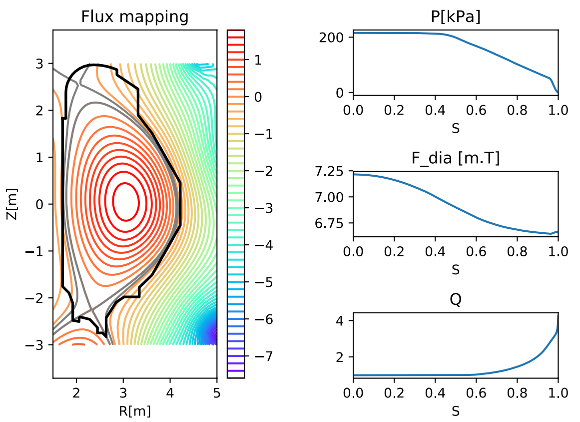

Figure 1 – Plasma equilibrium used in the numerical simulations

The plasma equilibrium, derived from CREATE toolset [2], combines internal kinetic profiles from CRONOS [3] with operational plasma shape requirements namely the strike points, X-point positions and right outward gap to the first wall. The plasma density and temperature profiles used for are shown Figure 2 for the electron species. A Z_{eff}~[1.6-3] across de plasma is considered since a small concentration of fully stripped Carbon impurity is assumed.

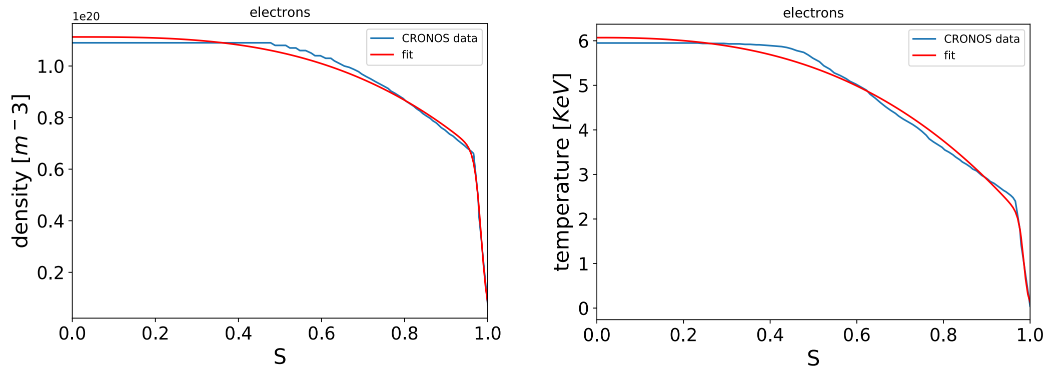

Figure 2 – Electron density and temperature profiles from CRONOS (blue) and the analytical fit (red) used in the numerical simulations.

The NBI distribution functions are obtained from the ASCOT [4] simulation package. Independent runs were made using only the positive neutral beam sources (11 beam sources with 85keV injection energy for total of 22MW with counter-current beams not in use) and the negative beam sources (500keV for total of 10MW) to better infer the individual role in MHD stability of the different sources. The slowed down integrated distribution functions as a function of energy and "radius" for the two setups are shown in Figure 3 and 4 respectively.

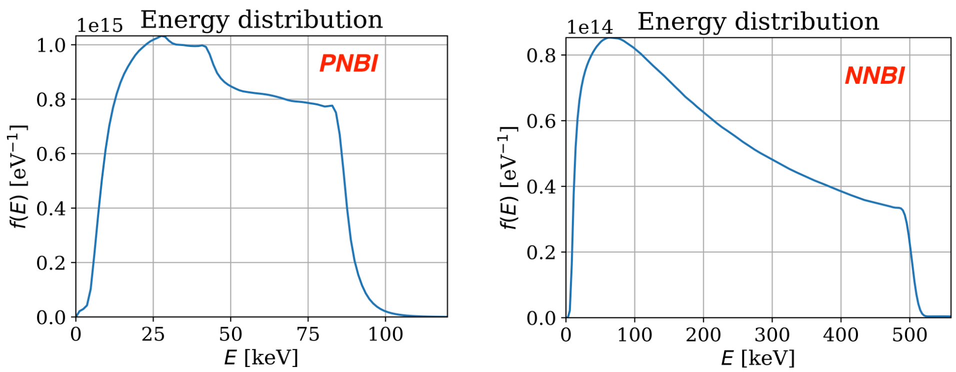

Figure 3 – Slowed down energy distribution function for the positive NBI beams – "PBNI" (left) and negative NBI beams – "NBNI" (right).

The deposition of the two beam types is clearly different since the NNBI system, owing to the energy and alignment, is capable of penetrating further into the core plasma region. One should note though that neither energy nor radial distribution of the energetic ions reveals details essential to the physics of AE stability e.g. gradients of the distribution function and normalized canonical toroidal angular momentum $P_\phi = Ze\psi + m_{ion}F(\psi)V_{//}/B$ where F is the

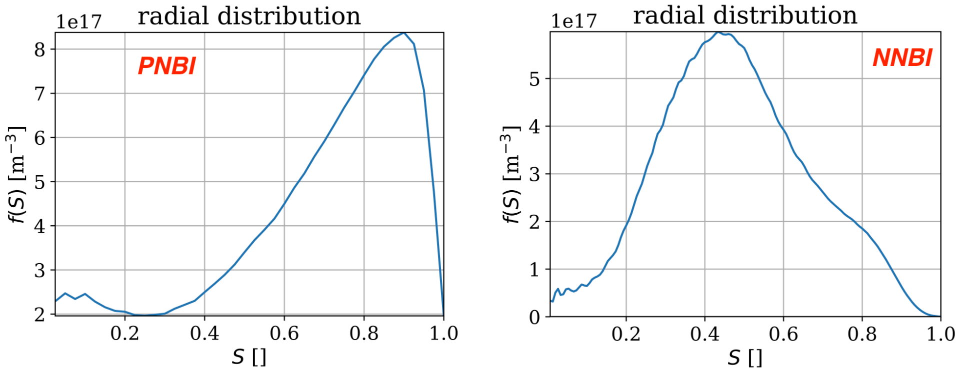

Figure 4 – Slowed down radial distribution function for the positive NBI beams (left) and negative NBI beams (right).

diamagnetic function, B the total magnetic field, ψ the poloidal flux, Z the charge of the energetic ion of mass m_{ion}. In particular, a careful analysis of the distribution function for co/counter passing particles in constant of motion space (P_ϕ, E, μ) where μ is the particle magnetic moment, showed that, contrary to a typical Maxwellian distribution, fine local features i.e. gradients can occur on energy and "radial" coordinate.

III – Modeling chain and results

The AE stability of the given scenario was analysed with ASPACK package, comprising here the high resolution plasma equilibrium HELENA [5], linear MHD stability MISHKA [6] and drift-kinetic CASTOR-K [1,7] codes. With a plasma boundary cut at 99.7% of the separatrix flux, an equilibrium is generated with HELENA and a scan in toroidal mode number from n=1-25 (drift-kinetic limit for 100keV particles and modes located at mid-radius) was performed with MISHKA with frequencies up to 2.7 times the Alfven frequency on axis (~188kHz). Any MHD mode crossing the ideal MHD continuum spectra is considered damped and not analysed by CASTOR-K. A total of 224 modes where retained and the resonant energy transfer between the energetic particle distribution and the Alfven eigenmodes was calculated with CASTOR-K. The results are summarized in Figure 5, showing the normalized growth rate (to Alfvén frequency on axis) calculated for all modes using the *PNBI* and *NNBI* beam source configurations. The color table used indicates the mode support/radial location or normalized mode frequency. It is clear from Figure 5 that predominantly mid-radius/edge modes (S>0.5) are driven unstable (TAE gap type modes) in agreement with the location of negative radial gradients of the distribution function in P_ϕ. Radial location alone doesn't warrant instability since it is evident that some outer modes, with mode frequency in EAE gap and above, are stable owing to an increased stabilizing effect from the energy gradient that scales linearly with mode frequency e.g. blue symbols in Figure 5 (top left) with negative growth rate.

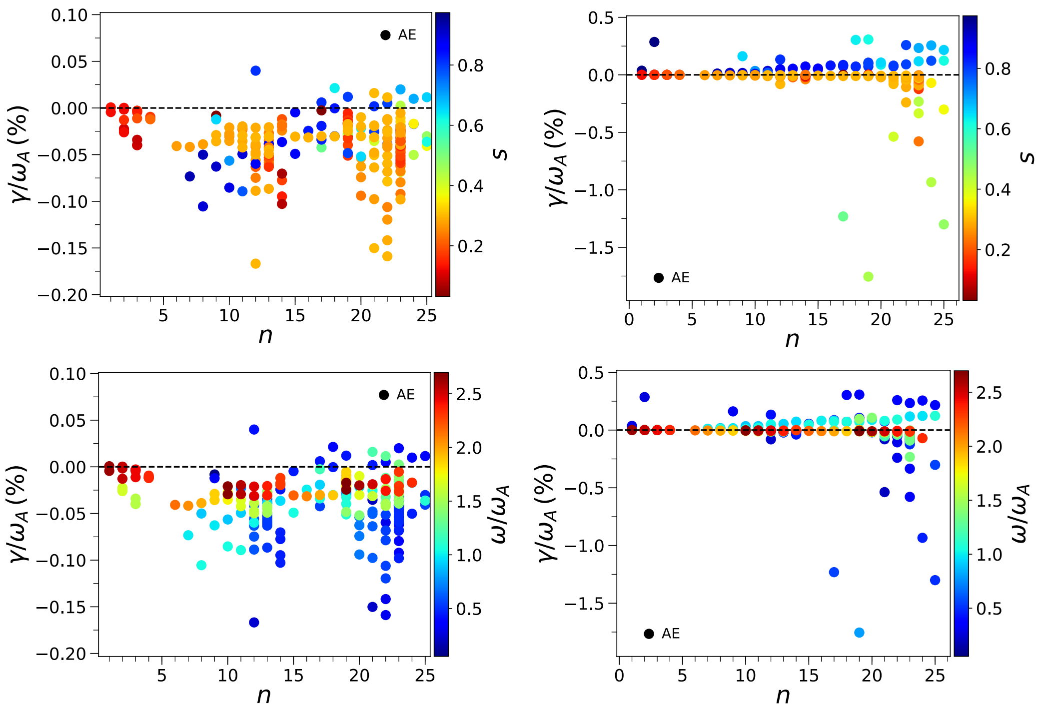

Figure 5 – Normalised growth rate of AEs with respect to positive NBI beams only (top/bottom left) and negative NBI beams only (top/bottom right) colored by radial location and normalized frequency.

IV – Conclusions

The Alfven Eigenmode stability of the working Scenario 3 of JT-60SA has been addressed using CASTOR-K using computed distribution function by ASCOT mapped to constant of motion. The energetic particle drive/damping on mode stability is found to be consistent with the slowed down distributions obtained. When considering Landau damping from thermal ion population (average 2% normalized damping), the mode drive imparted by primarily the negative beam sources is however insufficient to provide net mode growth.

Acknowledgements

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