3rd Quarter report (06/29/2007)

N. N. Gorelenkov, R. V. Budny, G.J. Kramer, J. Manickam, D. McCune
Princeton Plasma Physics Laboratory, Princeton University

Quarterly Milestone: Analyze the hybrid shear discharges, performing a parameter scan to determine the linear stability of toroidal mode number n = 1-15 TAE modes.

Executive summary. *The third quarter milestone was met. Similar to the 2nd quarter we performed numerical simulations of the stability of Alfvén Eigenmodes with frequencies up to the frequency of the TAE gap and n ranging from 1 to 20, but this quarter it is for the hybrid ITER plasmas. Five different equilibria were studied with the NBI injection angle varied in order to investigate the possibility of TAE stability control. We found that the hybrid plasma in general more unstable due to higher ion temperature. Most unstable cases are when the NBI is aimed slightly off axis,* $10-20cm$ *vertically away from the midplane. On-axis heating was marginally stable due to strong ion Landau damping. As in the case with the monotonic* $q-$*profile, NBI ions strongly contributed to the instability and can be used for TAE stability control.*

The NOVA-K MHD-kinetic-hybrid code is used to study TAE stability the same way it was used in the previous quarter. The input from TRANSP code modeling provides NOVA with the plasma and fast ion profiles. Five plasmas of the list reported in quarter 1 milestone report, Table III, are analyzed in this quarter simulations. This time we set up the injection geometry in such a way that the beam is aiming above the magnetic axis, which is different to the normal shear plasma, where injection was below or into the midplane.

Hybrid plasma differs from the monotonic q-profile, elmy H-mode plasma in a way that the q-profile has more complex structure. As one can see from Fig. 7(right) of the first quarter report, the current drive (mostly from NBI) introduces local reversed shear near the plasma center. This is very important equilibrium property for the stability study as the region of low shear is a potential location of such narrow modes as low shear TAEs and RSAEs.

Ideal MHD continuum and TAE spectra. In Figure 1 we show the MHD continuum for ITER plasma with off-axis NBI aiming at $10cm$ above the midplane, which is introduced in this quarter study to see the sensitivity of the TAE stability to the inclination angle. Two most unstable modes in this case are also shown in that figure. Both are close to the low shear region and are unstable. Such a case, when several modes closely located can potentially lead to resonance overlap and strong radial transport of fast ions.

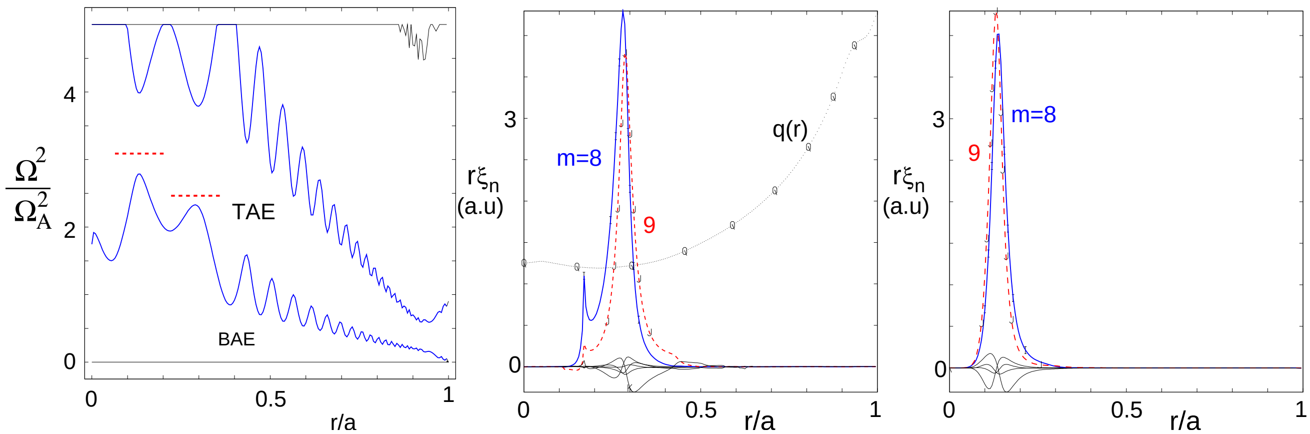

Figure 1: Ideal MHD $n = 7$ continuum for ITER hybrid plasma run #40500t03 (left figure) and two most unstable low shear localized TAE poloidal harmonic radial structures for the case with NBI aiming 10cm above the magnetic axis. Center figure represents the radial structure of TAE with $\Omega^2/\Omega_A^2 = 2.41$ and right figure corresponds to TAE with $\Omega^2/\Omega_A^2 = 3.09$, where NOVA uses normalization $\Omega_A = v_{A0}/q_a R$. The radial extent of these modes is shown in the left figure as dashed lines. Vertical position of these lines corresponds to the normalized eigenfrequency.

Fast ion radial profiles. One problem we had to addressed this quarter when we modeled the hybrid plasma is the non-monotonic radial dependence of beam ion and fusion alpha beta profiles. The profiles are given in Figs.8 of the first quarter report. The fluctuations in the radial profiles of fast ions seem to result from the Monte-Carlo noise of the TRANSP code. In order to cope with this we apply the smoothing procedure. Fitted profiles for fast ions used in NOVA simulations are shown in Figure 2. This way we avoid overestimation of localized TAE solutions, when their amplitude is peaked at the local strong fast ion pressure gradient region.

The beam ion distribution function model is described in the previous quarter report, Eqs.(1,2,3). It turns out that the key parameters for the distribution function are not sensitive to the plasma scenario because of large size of the plasma and relatively weak change in the inclination angle of NBI. The same parameters for the beam ion distribution function are used in this quarter simulations. Namely injection pitch angle and the pitch angle width:

$$\chi_0 = 0.7,\ \delta\chi = 0.12. \tag{1}$$

TAE stability in hybrid plasmas. We present stability simulation results with α-particles only and with alphas and beams contributing to the drive in Figs. 3, 4, and 5 for five hybrid plasmas.

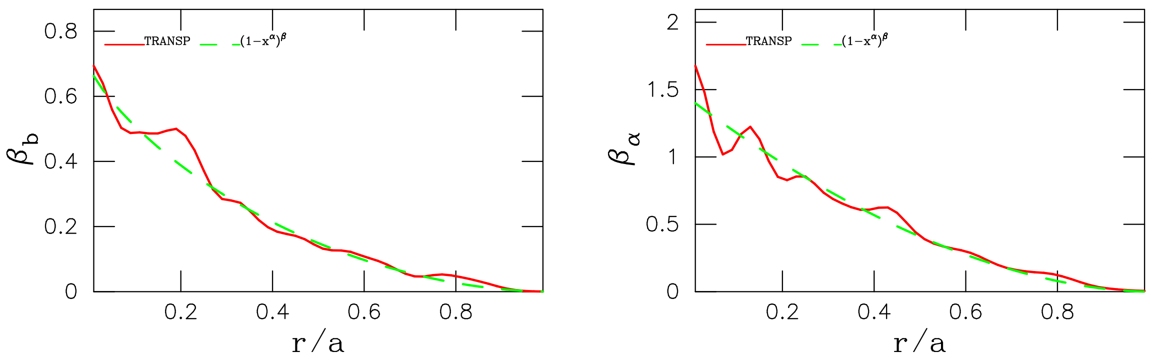

Figure 2: Example of the TRANSP produced NBI (left) and fusion alphas (right) beta profiles (in %) for ITER hybrid plasma run $40500T04$. Shown as solid lines are the profiles from TRANSP code. Shown as dashed lines are the fitted profiles, used in NOVA simulations.

Negative (positive) growth rates indicate that the modes are stable (unstable). In general hybrid plasmas is more unstable due to the higher fusion alpha pressure. This is due to larger plasma temperature, which is about $T_{i0} = 29keV$, whereas it is $T_{i0} \simeq 20keV$ in H-mode plasmas. So more fusion alphas are present which density grows faster than the damping rate from ions (Landau damping).

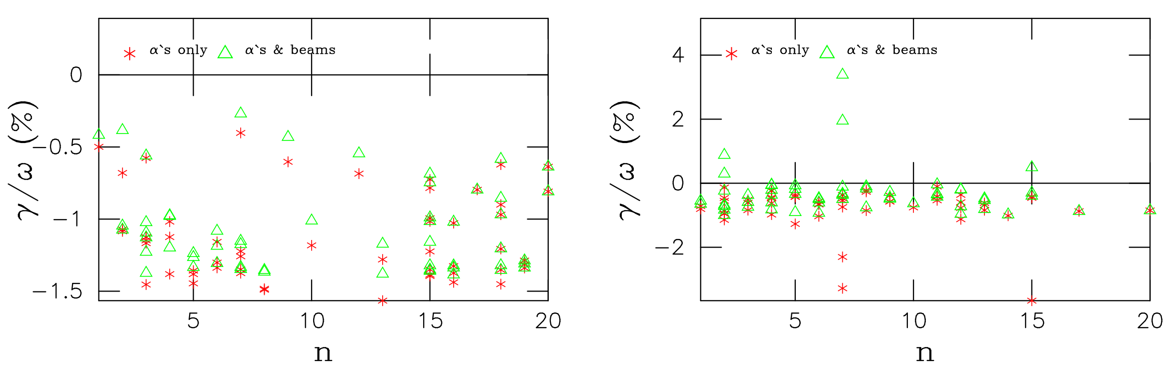

Figure 3: Toroidal mode number dependence of the AEs growth rates for the instabilities driven by alpha particles only ($*$ points), and driven by both NBI ions and alpha particles ($\triangle$ points). Results are for NBI aiming $Y = 20cm$ above plasma axis, ITER TRANSP run #$40500T04$ (left figure) and for the run #$40500T03$ with $Y = 10cm$ (right figure).

For the hybrid plasma we plot the maximum growth rate of TAEs vs. vertical deviation of the NBI aiming point from the magnetic axis, Fig, 6. In consistency with previous studies the on-axis beam injection seems to be most stable. Aiming $10cm$ above produces instability and aiming $20cm$ above the axis produces TAE stable plasma. Aiming $20cm$ and $40cm$ below the axis again makes

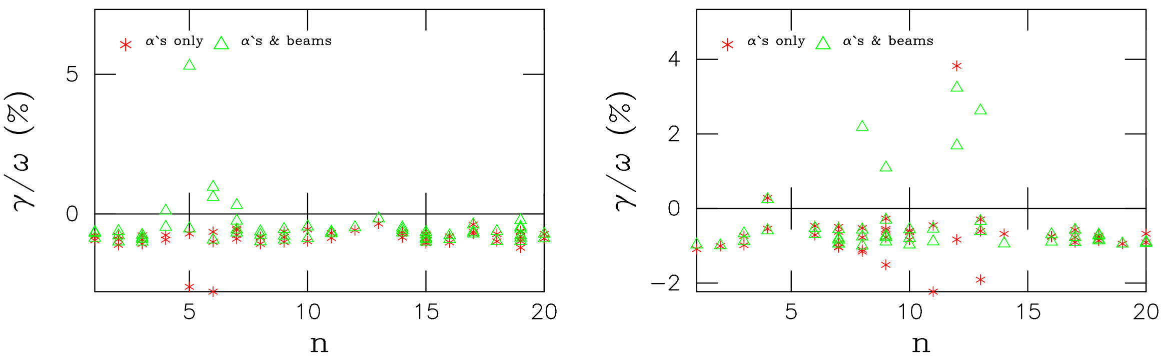

Figure 4: The same as in figure 3 but for $Y = -20cm$, $\#40500A06$ run (left figure) and for the run $\#40500T02$ with $Y = -40cm$ (right figure).

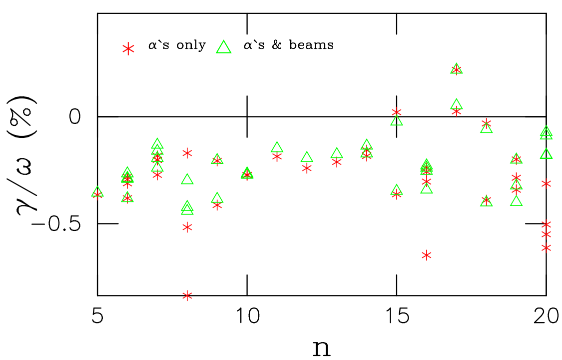

Figure 5: The same as in figure 3 but for $Y = 3cm$ (on-axis heating), $\#40500A04$ run.

the plasma unstable. The unstable TAEs are localized to the region of low shear within $r/a < 0.5$ in most of the cases of hybrid plasmas investigated. However weakly unstable global TAEs outside $r/a = 0.5$ are also present. This means that in hybrid plasmas fast ion transport can be more significant as the center of the plasma and the plasma edge are coupled via global TAEs. More studies have to be done for the nonlinear TAE problem and associated global radial transport of fast ions. NOVA is important tool in this as it can predict which n's are most unstable.

Another important result which is relevant for the TAE stability problem is that we identified the most important damping mechanisms. The most important is the ion Landau damping on thermal ions and electrons, especially for core localized modes. For the edge localized and global TAEs electron collisional damping dominates. At high-n numbers radiative damping limits the unstable modes. Continuum damping is important but in the NOVA model is not a function of the mode number. It can be often avoided if the mode structure is localized away from the continuum, such as in the cases shown in 1.

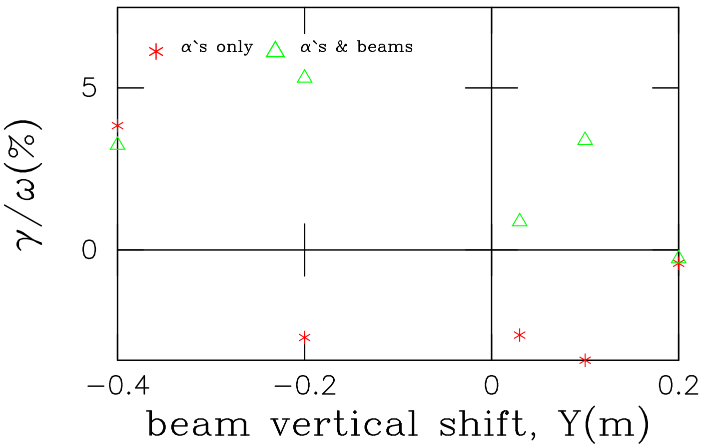

Figure 6: Most unstable TAE growth rates vs. vertical deviation of the beam injection from the magnetic axis for hybrid plasma.