4th Quarter report (09/29/2007)

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Quarterly Milestone: Analyze the reversed shear discharges, performing a parameter scan to determine the linear stability of toroidal mode number n = 1-15 TAE modes, and prepare a comprehensive review of the TAE stability of ITER discharges in the three operating regimes.

Executive summary. *The forth quarter milestone was met. Reversed shear ITER plasma scenario (or advanced tokamak - AT) was analyzed. The stability of Alfvén Eigenmodes with frequencies up to the frequency of the TAE gap and n ranging from 1 to 20 was simulated. Three ITER AT plasmas were modeled with different values of the shear reversal, which was changing from being close to the hybrid to a well reversed. We have found that the plasma in the most reversed shear configuration is the most unstable. This is due to much wider TAE gap in the strongly reversed case and generally localized solutions near the point of* q_{min}*, which is close to the maximum gradients of alpha and beam ion pressures. As in the case with the monotonic* $q-$*profile and hybrid, NBI ions strongly contributed to the instability and can be used for TAE stability control.*

In this quarter we focused on scanning the safety factor profiles from weakly reversed, close to the hybrid scenario (studied in the third quarter) to a strongly reversed, so called steady state. NNBI aiming was approximately the same and was chosen to optimize the beam current drive.

Choice of plasma parameters. We extended reversed shear (RS) or advanced tokamak (AT) plasma scenario presented in quarter 1 studies to two more plasmas. The following table I lists these three plasmas. Since we already studied the sensitivity of the TAE stability to NNBI inclination angle it seemed interesting to explore how different q-profiles effect the AE stability. Variations in q-profiles are achieved in such complex AT ITER plasmas via timing of application of ICRH, changing energy of NNBI and Ohmic current. These runs are based on TSC runs with ad hoc transport since no adequate GLF23 temperature simulation has been found. In addition slightly peaked electron density profiles assumed. Also we explored the possibility of having high beta normal according to the table. The main effect on TAE stability is via the q-profile variations. In particular the location and the wide radial extent of the low shear region result in the more unstable TAEs as we stressed throughout the milestone studies. That is why this particular study of the TAE stability is important for the planning of AT plasma experiments in ITER.

TRANSP id	# in figure legend	Y (cm)	β_N	I_p (MA)	E_b (MeV)	$n_e/n_{Greenfield}$	Fusion Power (MW)
60000T02	1	-40	3.3	8-9.5	1	0.82	493
60000T04	2	-20	3.3	8-9.5	0.8	0.97	400
40000B11	3	-20	2.3	12	1	0.47	315

Table I: A list of TRANSP runs along with the value of NNBI vertical displacement, Y, of its injection line at its nearest point to its tangential radius for AT plasma.

Radial plasma profiles are given in Figures 1 and 2. One can see that stronger reversed shear is achieved by having off-axis beam ion pressure profiles (and current drive) as in the case of TRANSP run $40000B11$.

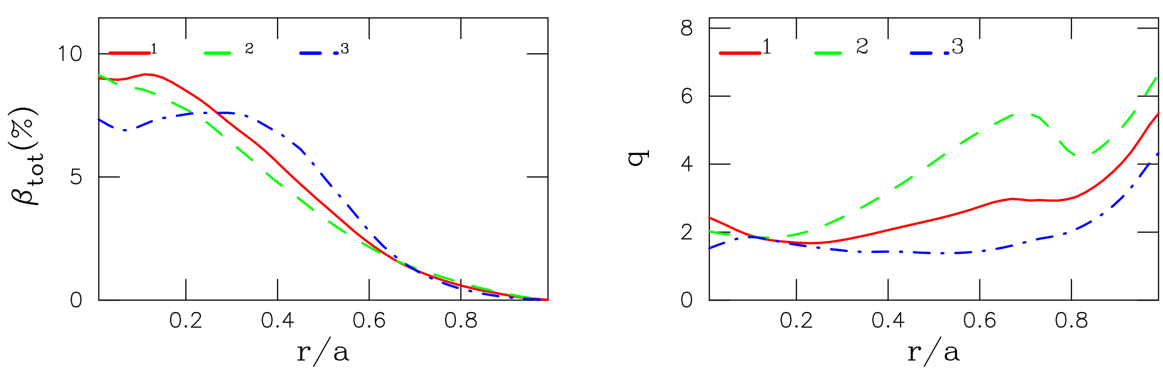

Figure 1: Total plasma beta (left) and safety factor profile (right) for reversed shear ITER plasmas.

Ideal MHD continuum and TAE spectra. In Figure 3 we show the MHD continuum for ITER AT plasmas of interest. We note two distinct features of these continua.

First, plasmas 1 and 2 have much wider BAE gap. This produces a push to the TAE frequencies, so that the TAE gap becomes less aligned radially. This is expected to have a stabilizing effect by introducing more continuum damping. In addition higher beta of plasmas 1 and 2 push TAE frequencies into the gap especially near the center. This is stabilizing effect meaning that certain TAEs will not exist in those plasmas.

Second, comparing Figures 3 with q-profiles of Figure 1 (right) we can also conclude that the widest TAE gap corresponds to the safety profile with the widest region of the low shear, plasma

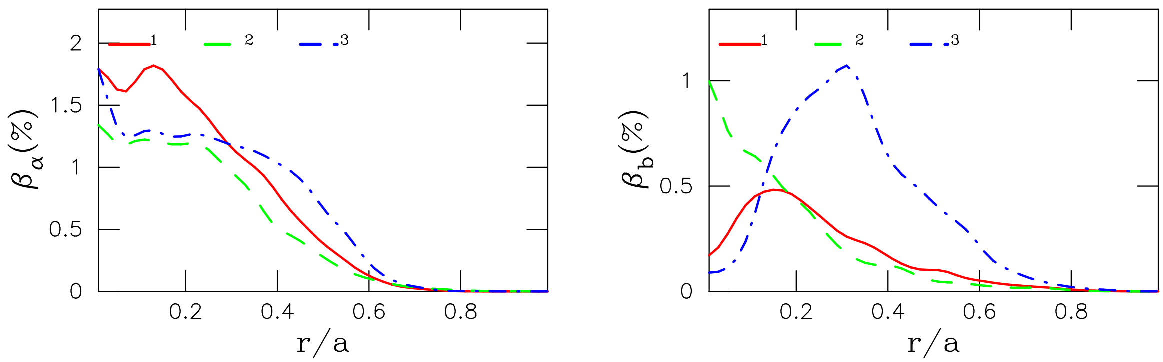

Figure 2: Fusion alphas, β_α, and NNBI confined ion, β_b, betas.

#3, Figure 3 (3). This implies that such plasma can be prone to TAE instabilities. Next we check this by rigorous numerical study.

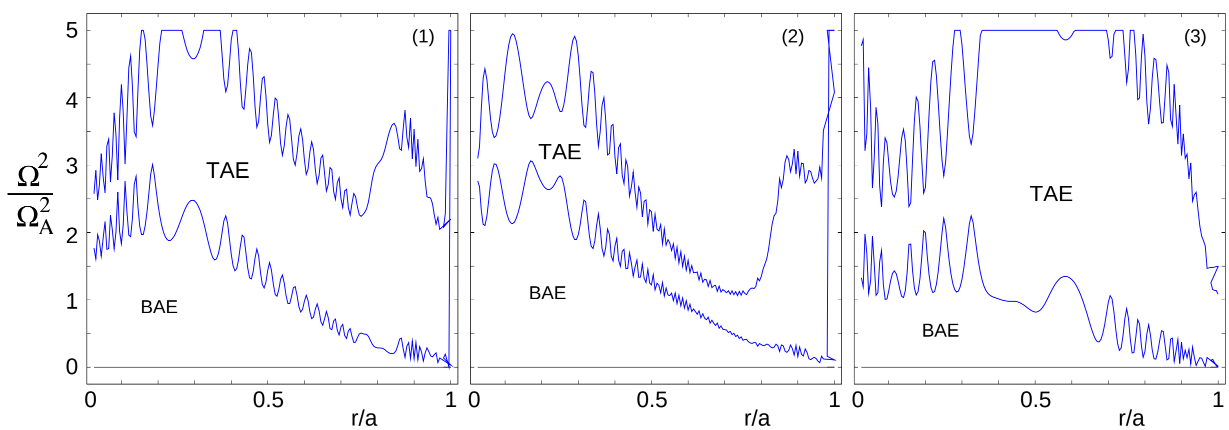

Figure 3: Ideal MHD $n = 10$ continuum for ITER reversed shear plasmas numbered #1, 2, 3 in table I. Frequencies are normalized to $\Omega_A = v_{A0}/q_a R$.

Figures 4 summarizes such study. As we expected the least unstable case is plasma #2 (60000T04, stability shown in figure 4, center), which has the most narrow TAE gap, figure 3, center. Thus stronger continuum damping is expected. In the opposite case of the strong reversed shear plasma, #3, (40000B11, stability shown in figure 4, right) TAE modes are localized right in the strongest alpha particle and beam ion pressure gradient as can be seen in the figures 2.

Most interesting is that strongly RS plasma in addition to having a few unstable localized solutions, such as $n = 11, 12$. we found many weakly unstable, but global modes, both TAEs and EAEs (ellipticity induced Alfvén eigenmode). Example of the most unstable $n = 11$ TAE and weakly unstable $n = 2$ EAE are shown in figure 5. Due to their global mode structure such multiple instabilities appearing at $n = 1$ to $n = 11$ can be very dangerous for fast ion confinement due to the expected closeness of the wave-particle resonances to each other in the phase space. As a result even with small mode amplitudes (small drive) resonances can overlap and enhanced transport may develop possibly causing such effects as avalanches.

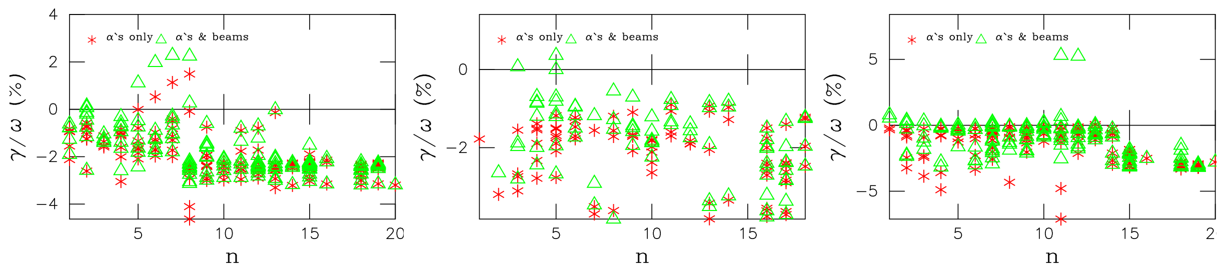

Figure 4: Toroidal mode number dependence of the AEs growth rates for the instabilities driven by alpha particles only ($*$ points), and driven by both NBI ions and alpha particles ($\triangle$ points). Results are for ITER reversed shear plasmas numbered $\#1, 2, 3$ listed in table I, shown in left, center and right figures, respectively.

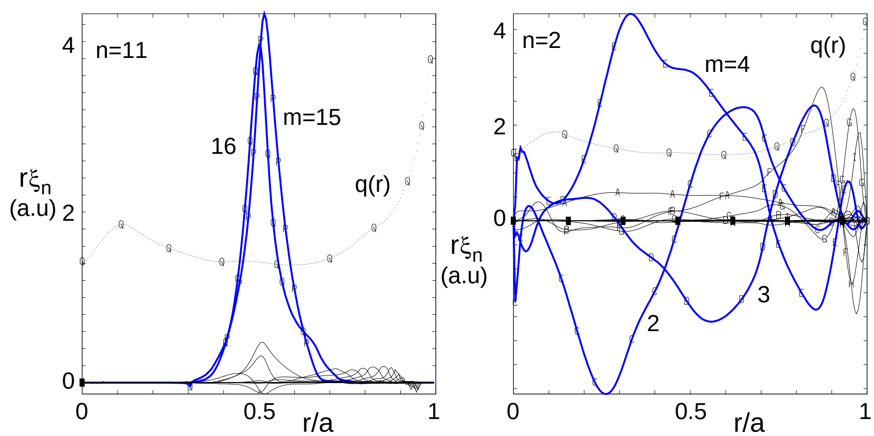

Figure 5: Left figure represents the radial structure of the most unstable localized TAE in strongly reversed ITER AT plasma #3. Left figure TAE has $n = 11$ and $\Omega^2/\Omega_A^2 = 2.12$. Right figure corresponds to EAE with $\Omega^2/\Omega_A^2 = 6.7$ and $n = 2$, which is weakly unstable, but more global.

We present the example of the stability calculations for the modes shown in figure 5 in Table II. In this cases beam drive seems to dominate the instability. This is due to strong peakedness of its pressure profile outside the plasma center.

Overall AT plasmas (as well as the hybrid plasma) is the most unstable with the damping rates for the unstable modes approaching $3 - 5\%$. One of the dangerous property of the TAEs in AT

n	Ω^2/Ω_A^2	$f(kHz)$	$\gamma_{iL}/\omega\,(\%)$	$\gamma_e/\omega\,(\%)$	$\gamma_{continuum}/\omega\,(\%)$	$\gamma_{radiative}/\omega\,(\%)$	$\gamma_\alpha/\omega\,(\%)$	$\gamma_{NBI}/\omega\,(\%)$	$\gamma_{\sum}/\omega\,(\%)$
11	2.12	84.5	-2.15	-0.03	-0.05	-4.49	1.93	10.1	5.3
2	6.7	149.8	-0.18	-0.1	0	0	-0.15	0.76	0.33

Table II: Growth and damping rates calculation for $n = 11$ TAE and $n = 2$ EAE in a strongly reversed shear ITER plasma. In the table various contributions to the growth rates are presented, such as γ_{iL} ion Landau damping, γ_e electron Landau and collisional damping, $\gamma_{continuum}$ continuum damping, $\gamma_{radiative}$ radiative damping, γ_α alpha particle drive, γ_{NBI} beam ion drive, and total growth rate $\gamma_{\sum}$ normalized to the mode frequency.

plasma is that there are much more unstable modes, which can result in the multiple mode induced transport of fast ions in ITER.