Observation and Analysis of Resistive Instabilities in Negative Central Shear DIII–D Discharges with L–mode Edge

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INTRODUCTION

In DIII–D plasmas with L–mode edge and negative central shear (q_{axis}-q_{min} ~0.3 to 0.5), an interchange-like instability has been observed [1]. The instability and a subsequent tearing mode cause reduction of the core electron temperature and plasma rotation, and therefore the instability affects discharge evolution and the desired high performance is not achieved. Stability analyses indicate robust ideal stability, while the Resistive Interchange Mode criterion is marginal and the instability appears to be localized intially. Based on this, we believe that the mode is, most likely, a Resistive Interchange Mode. The amplitude of the instability is correlated with the location of the q_{min} surface and inversely with the fast-ion pressure. There is indication that the interchange-like instability may be "seeding" the tearing mode that sometimes follows the interchange-like instability.

OBSERVATION AND ANALYSIS OF THE INTERCHANGE-LIKE INSTABILITY

The observations were made in a plasma with a double-null shape. At the time of the onset of the instability, the current (=1.0 MA) is being ramped during neutral beam heating in order to produce a broad current profile with a central region of negative magnetic shear, $q'<0$. It may be noted that $q'<0$ and $p'<0$ are usually destabilizing for the Resistive Interchange Mode. The pressure profile is normally peaked without any transport barriers. The density of the plasma is ~$2.5\times10^{19}/m^3$, the plasma normalized beta β_N is ~1.0 and the minimum safety factor q_{min} is ~2. Mode analysis of the magnetic probe data shows that the instability has a toroidal mode number of 1 (coherence ~0.99).

Figure 1 shows the amplitude of the Mirnov signal for several discharges. For example, in discharge 106324, the interchange-like mode starts at about 935 ms, then decreases to a minimum amplitude at about 960 ms, and a tearing mode occurs beyond that for a duration of ~80 ms. Figure 2 shows the amplitude and phase variation of ECE (Electron Cyclotron Emission) oscillation (midplane measurement) at the time the interchange-like instability is near its peak amplitude (plus symbol). The instability has nearly the same phase over a broad region and the amplitude is symmetric on either side of the axis (interchange-like instability with m=even). In the core, $\rho<0.2$, a low amplitude m=odd mode appears be present. In contrast, for a later time slice during a tearing mode (open circles), a 180° phase change at ρ~0.3 can be seen, indicating a magnetic island. ECE signals show that at the onset, the mode is localized and then grows in both width and amplitude.

Ideal stability analyses have been carried out using the codes GATO and DCON and these indicate robust stability (recomputed equilibria using the code TEQ with plasma

pressure increase of 25% and significant q profile variations also give ideal kink stability). The criteria D_I (>0 for Mercier instability) and D_R (>0 for resistive interchange mode) were also calculated. D_I and D_R are related by the expression [2] $D_R = D_I + (H-0.5)^2$, where

$$H = \frac{\mu_0 p' V' f}{4\pi^2 q'} \left[\left\langle \frac{1}{|\nabla\psi|^2} \right\rangle - \frac{\left\langle B^2 / |\nabla\psi|^2 \right\rangle}{B^2} \right] \quad . (1)$$
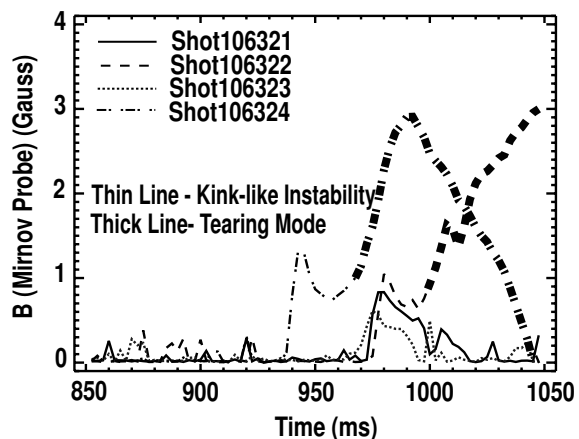

Fig. 1. Amplitude of Mirnov signals for several discharges with the interchange-like mode. The signal of a tearing mode that follows in some shots is shown by the thicker line.

The criterion D_R is marginal for all the discharges with the instability and is robustly negative for discharges without the instability. Figure 3 shows the comparison of the criterion D_R for a discharge with the instability and one without. Within the uncertainties of the equilibrium reconstructions, $D_R \approx 0$ for the discharge with the instability.
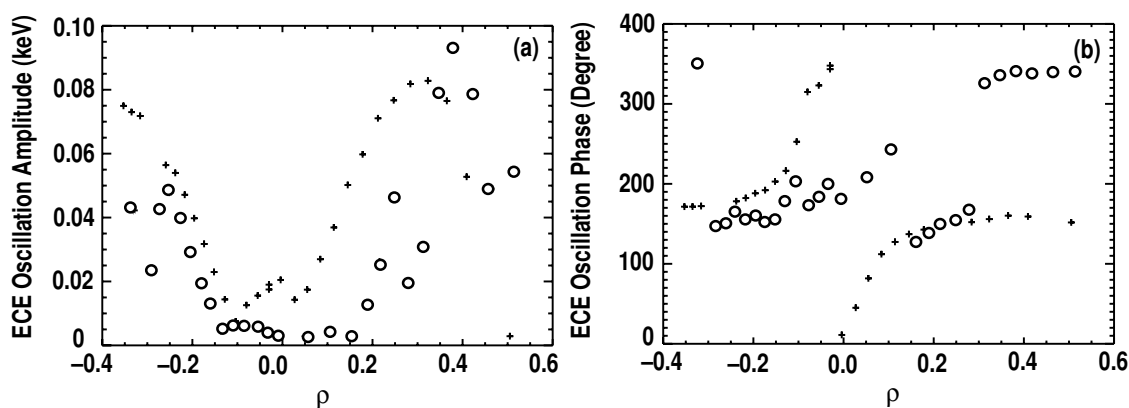

Fig. 2. Radial profiles of (a) amplitude and (b) phase of ECE oscillations in discharge 106324, comparing timeslices with interchange-like instability (crosses, 955 ms) and tearing mode (open circles, 995 ms). Negative ρ represents measurements on the inside of the minor axis.

The amplitude of the interchange-like mode is not correlated to the value of the D_R criterion but is correlated to the location of the q_{min} surface-$\rho(q_{min})$ and inversely to the fast-ion pressure (computed using the code ONETWO). Measured neutron generation does not show any decrease during the instability period. This suggests that the appearance of the interchange-like instability is not caused or aided by the fast-ions.

Therefore, the instability has the following characteristics:

- ECE measurements show that the oscillations at nearly all flux surfaces are in phase, unlike in a tearing mode, where an abrupt phase reversal of 180° is found. Therefore, this is an interchange-like instability.
- Ideal stability analysis shows robust stability to ideal modes.
- The amplitude of the instability is inversely correlated to the fast-ion pressure and no significant decrease in neutron generation occurs during the period of instability indicating that the mode is, most likely, not caused by fast-ion modes.

- The Resistive Interchange criterion is marginal for all the discharges with the instability and is robustly negative for discharges without the instability.

Based on the above, we believe that the instability is, most likely, a Resistive Interchange Mode. Detailed calculations using the codes MARS and PEST-III are being carried out to confirm this. The Resistive Interchange Mode has been observed [2] in DIII–D plasmas before, but this is the first time it has been observed at these low β_N values where the ideal modes are robustly stable.

If the initially localized interchange-like mode is a Resistive Interchange Mode, does it remain the same mode as it widens and grows? Since the mode characteristics remain
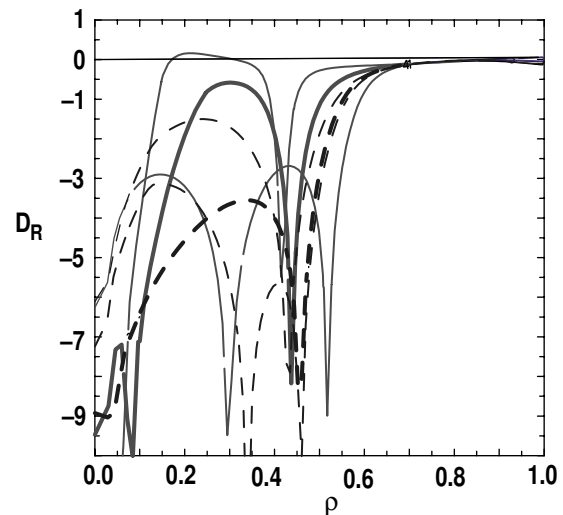

Fig. 3. The criterion for Resistive Interchange Mode. Solid line – discharge 106324 with the interchange-like instability. Dashed line – discharge 106328 without any interchange-like instability. The variation of the criterion within limits of uncertainties in MSE measurements and pressure calculations are also shown in light lines.

the same in all other respects, it would seem that it is the same mode. We speculate that the broadening of the mode may be similar to the broadening of a tearing mode, which is also localized in linear theory but is broadened by nonlinear effects.

RELATIONSHIP BETWEEN THE INTERCHANGE-LIKE INSTABILITY AND THE SUBSEQUENT TEARING MODE

The displacement of the flux surface was calculated from the ECE oscillation amplitude using the relation $\xi_{ECE} = \left[\delta T_e^{ECE} / dT_e^{ECE} / dr\right]$ where δT_e^{ECE} is the 0 to peak amplitude of the electron temperature oscillation measured by ECE at the location of the maximum amplitude of the mode and dT_e^{ECE}/dr is the measured gradient of electron temperature. This displacement, just before the onset of the tearing mode (or faster decay of the interchange-like mode), is plotted versus an approximate ion banana orbit width in Fig. 4. It appears that there is a critical amplitude of the interchange-like instability for a tearing mode to follow. (The correlation with the banana orbit may not be significant since the banana width varies only over a small range). This suggests that the interchange-like mode may be directly "seeding" the tearing mode.

The profiles of D_R and D_I were calculated for several discharges for many time slices. Comparison (Fig. 5) of these profiles shows that the parameter D_R-D_I decreases significantly over the duration of the interchange-like instability in discharges with the tearing mode, while it remains nearly the same for the discharges with small interchange-like instability amplitudes and no tearing mode. It is seen that the magnitude of the change in D_R-D_I, is also strongly correlated with the amplitude of the interchange-like mode. On the other hand, since D_R-D_I depends only on the parameter H, this represents a change in the parameter H or change in p' /q' . The significance of this correlation with the appearance of the tearing

mode possible connection to the "seeding" of the mode is being investigated, using standard tearing mode theories [3].

CONCLUSIONS

An interchange-like instability, observed in negative central shear plasmas with an L–mode edge is, most likely a Resistive Interchange Mode. The instability is initially localized radially and then broadens, may be due to non linear effects as for tearing modes. There is evidence that the interchange-like instability may act as a "seed" for a subsequent tearing mode and a critical amplitude of the interchange-like mode has been observed. The significance of the variation of the parameter H or its value before the onset of the tearing mode is being investigated.
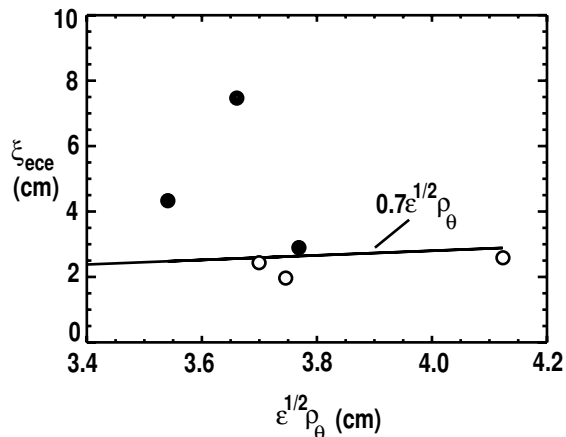
Fig. 4. The flux surface displacement due to the interchange-like instability. Filled circles – discharges with the tearing mode; unfilled circles – discharges without the tearing mode.
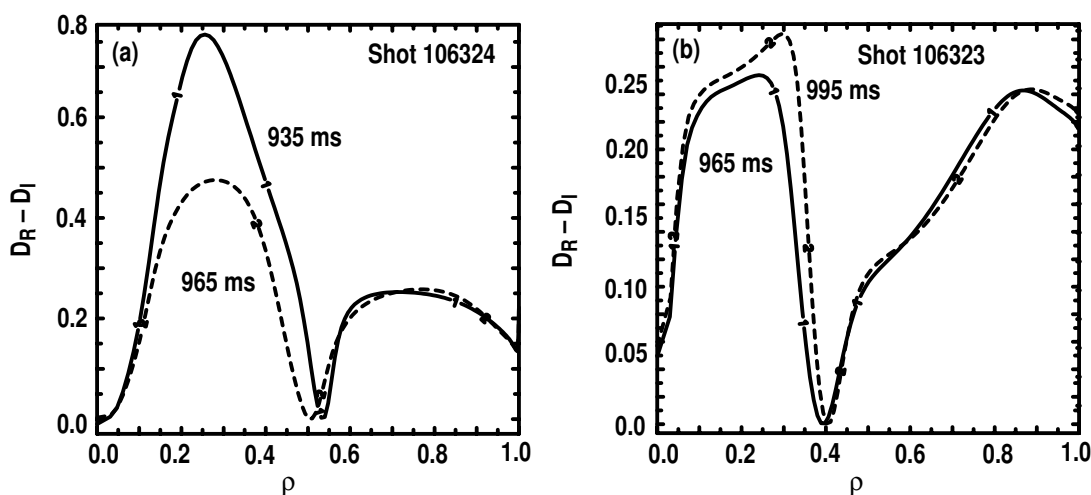
Fig. 5. The parameter D_R-D_I just before the start of the interchange-like mode and after the evolution of the interchange-like mode for a discharge with the tearing mode (left) and discharge without the tearing mode (right).

REFERENCES

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