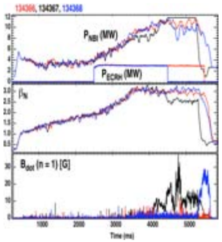
TEARING MODE STABILITY OF STEADY-STATE SCENARIO PLASMAS IN DIII-D

F. Turco, *ORISE*, T.C. Luce, J.R. Ferron, C.C. Petty, P.A. Politzer, A.D. Turnbull, *General Atomics*,
D.P. Brennan, *U. Tulsa*, M. Murakami, *ORNL*, T.A. Casper, C.T. Holcomb, *LLNL*

Background

Tearing mode stability is crucial for high-performance scenarios intended for steady-state operation. The appearance of tearing modes in DIII-D discharges leads to loss of energy confinement, and to a redistribution of the current profile that is not recoverable with the available non-inductive current drive sources. It has been routinely observed, namely in high-β quasi non inductive DIII-D discharges, that ECCD can prevent the mode formation, without a direct island stabilization.

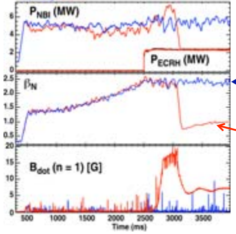
With and without ECCD:



- *ECCD absent*
- *ECCD trips*

The shot is unstable

Different ECCD deposition:



For the same β, only the broad ECCD deposition is stable

Broad
ρ ~ 0.25-0.55

Narrow
ρ ~ 0.4-0.55

Goals and method

☐ Observation of **current density profiles** -> identify patterns in the current evolution towards stability/instability:

→ *what type of evolution characterises unstable discharges?*
→ *what regions of the current profile are important?*

☐ Observation of the **type of modes** that end the high-beta phases:

→ *what can act on the modes stability?*

☐ Observation of the **effects of the EC current**:

→ *location, profile shape, power, timing*

PHASE (1)

☐ Apply **resistive stability models** in order to assess what the patterns are supposed to do:

→ *Evaluate stability of the equilibria*
→ *change the equilibria following the observed patterns*
→ *add ECCD to the equilibria*

☐ Attempt a **control of the discharge** using the acquired predictive capability: ECCD can correct the evolution of the plasma towards stability

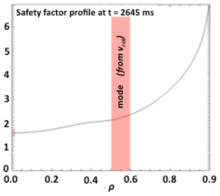
PHASE (2)

1. The current profile evolution: impact of the current gradient on the mode destabilization

Toroidal current (J_{tor}) profiles at the beginning of the ECCD phase (left) and at the time of the mode (right) **from the MSE measurements**:

- *n=1 mode at ρ ~ 0.5/0.6*
- *narrow ECCD deposition at ρ ~ 0.4÷0.55 / broad ECCD deposition at ρ ~ 0.25÷0.55*
- ***the current gradient builds up at ρ ~ 0.47***

The broad ECCD deposition keeps the discharge stable



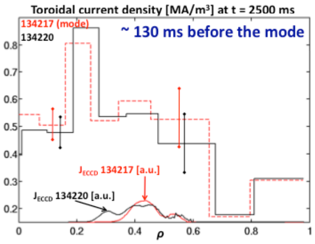
The current profile evolution towards the triggering of the mode shows

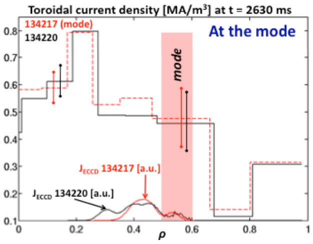
1. a pattern inside ρ ~ 0.2
2. a pattern between ρ ~ 0.3 and ρ ~ 0.8

We will focus on (2), since the changes inside ρ ~ 0.2 are less likely to impact on the tearing modes (ρ > 0.4), but the actual importance of (1) remains an open question.

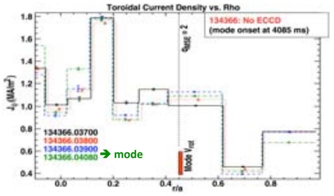
① *The current profile is flatter in the centre when a mode is triggered*

② *A greater **current gradient, of either sign**, is recurrently observed in the unstable discharges, localized just inside the mode position*



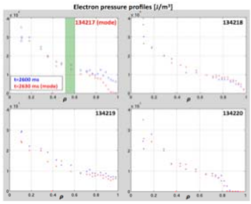


*When ECCD is not present (e.g. #134366) or the gyrotrons trip (e.g. 134227), a "hole" is left in the profile, and **the negative gradient appears to destabilize the mode:***

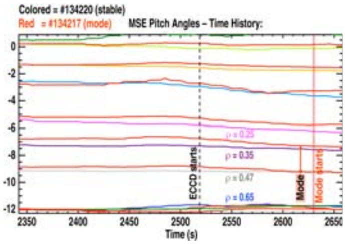


The pressure profiles do not change significantly

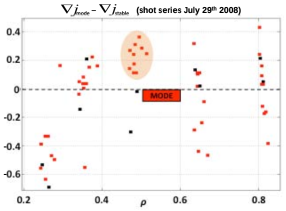
- *in the evolution towards the mode*
- *between stable and unstable discharges*

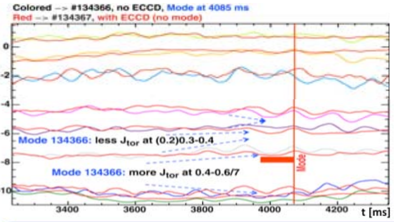


*The current profiles characteristics are confirmed by the **raw data evolution (MSE time history)**: the difference appears in channels 9 to 11 until the mode sets in.*

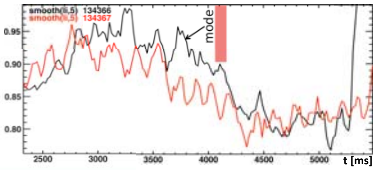


*A pattern is observed also evaluating the **current gradients** for all the discharges of the series: the difference between the "unstable" gradient and the "stable" ones is ~always positive at 0.45-0.49.*





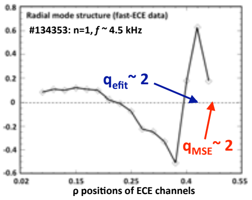
*The **internal inductance li** reflects the peaking in the #134366 current profile due to the "hole" that leads to the mode:*



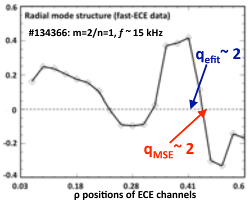
2. The nature of the modes affecting the confinement

m=2/n=1 or m=3/n=1, f ~ 4÷15 kHz

①
- *Tearing, slow growth (~200 ms)*
- *no burst of MHD activity beforehand*
- *a single toroidal number*



②
- *Faster growth (~10 ms): partly ideal?*
- *Bursts of MHD activity before the mode (f~20-50 kHz)*
- *often a n=2 is superimposed (e.g. a 5/2)*



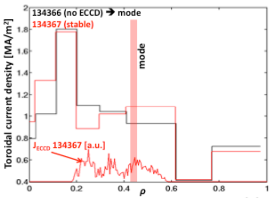
1. *The **current and pressure gradients** both affect the stability of these modes*
2. *The tearing stability index **Δ'** becomes very **sensitive to small changes in the equilibrium**, near ideal stability boundaries [1,2]*

[1] D. Brennan, PoP2002 [2] D. Brennan, PoP2003

3. The action of ECCD

◆ Stabilization has been observed for off-axis injections (ρ > 0.25)
◆ A narrow deposition *does not* provide stability
◆ **It is not a direct island stabilization!**

A high current gradient, of either sign, appears to be related to mode triggering



Negative gradients:

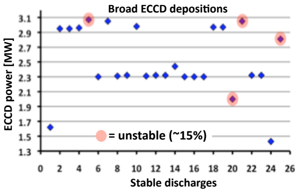
- *The rise of neutral beam power (→β)*
- *The current diffusion*
- *The sudden lack of ECCD (gyrotrons trip) can peak $J_{//}$ at the centre, and take away current at ρ~0.2-0.4:*

*The EC current prevents $J_{//}$ from dropping at ρ ~ 0.2-0.4 and **avoids the negative current gradient***

Positive gradients:

*ECCD in **narrow deposition** → **current density build-up close to a rational surface***
→ the higher current gradient destabilizes the mode

- **The ECCD power does not seem to be important for stability**
- **A few counter-examples (for both narrow and broad depositions) exist**



Summary and conclusions

The current density profile and evolution have been analyzed for high-β discharges with and without off-axis ECCD, and with different ECCD depositions, to assess their impact on the discharge stability.

- *A pattern in the $J_{//}$ evolution has been identified, in the external part of the profile: the unstable discharges are characterized by a **high or negative ∇j close to the mode location***
- *A few counter-examples exist: a transient high ∇j may not lead to instability*
- *The modes are mainly **n=1 tearing instabilities**: Δ' is sensitive to ∇j, ∇p, AND the equilibrium*
- *A broad **ECCD deposition** can prevent a negative ∇j, while a narrow one may cause a greater ∇j close to a rational surface*

The stability analysis of "phase 2" should focus on the region ρ ~ 0.35-0.65 of the current profile