Triggering Neoclassical Tearing Modes in NSTX

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Motivation

- Well-known that potentially unstable neoclassical tearing modes (NTMs) in tokamak plasmas are meta-stable.[1]
- In other words, such NTMs require some sort of externally applied "kick" before they can grow and saturate at large amplitudes.
- What can provide this kick?
- Generally assumed that kick is transient magnetic perturbation due to other modes that occur in plasma: e.g., sawtooth crashes, edge localized modes, other NTMs, etc.
- However, there has been very little systematic investigation into what properties a transient magnetic perturbation needs to possess in order to successfully trigger NTMs.
- Present talk is first step in such an investigation.

[1] R. Fitzpatrick, Phys. Plasmas **2**, 825 (1995).

EPEC Code

- EPEC code[2] simulates tearing mode dynamics in tokamak plasma using an asymptotic matching approach.
- Code incorporates magnetic equilibrium data (g-file) and profile data (p-file).
- Code includes toroidal coupling between different tearing modes.
- Code incorporates accurate neoclassical model that includes impurities[3] and allows calculation of bootstrap drive to tearing modes.
- For case of NSTX, external perturbation is provided by pulsing RMP coils. However, perturbation is allowed to rotate. This mimics multi-harmonic rotating magnetic perturbation generated by sawtooth crash, etc.

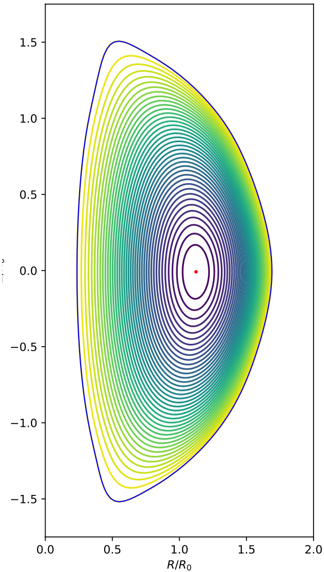
[2] R. Fitzpatrick, S.K. Kim, and J. Lee, Phys. Plasmas **28**, 082511 (2021).
[3] S.P. Hirshman and D.J. Sigmar, Nucl. Fusion **21**, 1079 (1981).

NSTX Shot 127317

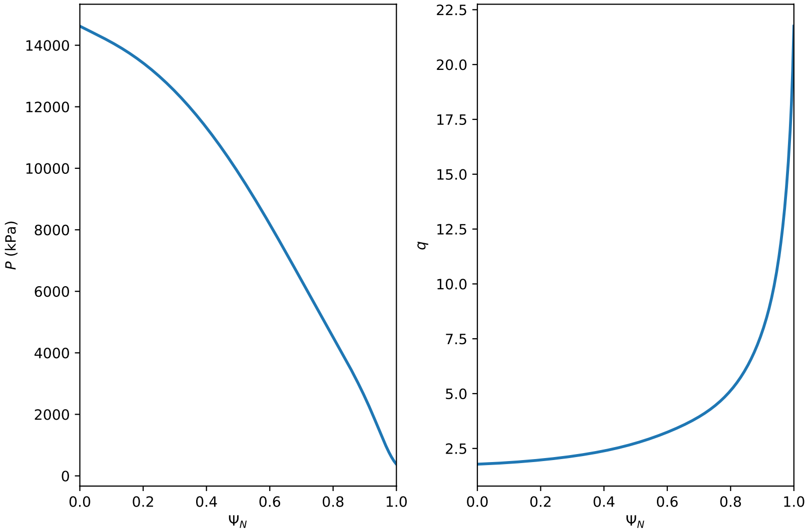
- NSTX shot 127317 was used in the ELM destabilization via externally applied non-axisymmetric resonant magnetic perturbation (RMP) experiments on NSTX.[4]

[4] J.M. Canik, et al. Nucl. Fusion **50**, 034012 (2010).

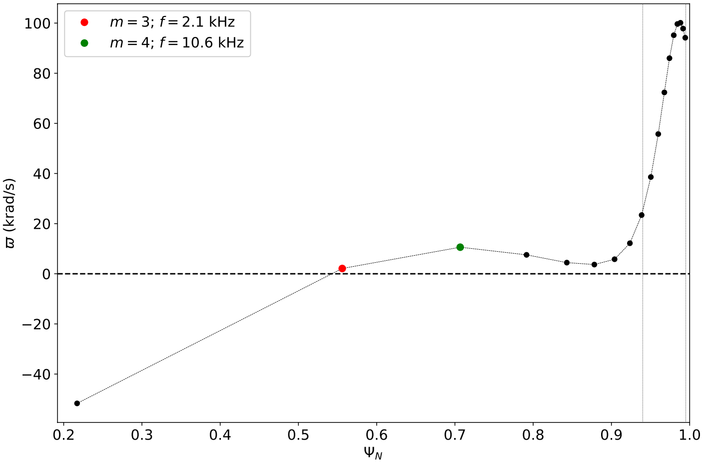
NSTX Shot 127317: Magnetic Flux-Surfaces



NSTX Shot 127317: Profiles



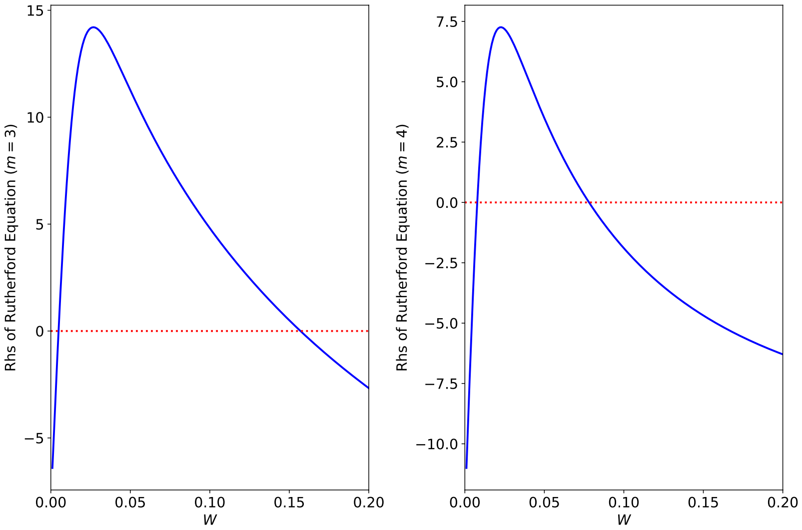
NSTX Shot 127317: $n = 1$ Natural Frequencies



NSTX Shot 127317: $n = 1$ Modes

- NSTX shot 127137 (400 ms) contains 18 $n = 1$ rational surfaces, corresponding to $m = 2$ through $m = 19$.
- Only two of these surfaces, $m = 3$ and $m = 4$, are potentially unstable to NTMs.
- The natural frequencies (i.e., frequencies that modes would rotate at if they were naturally unstable) of these modes are 2.1 kHz and 10.6 kHz, respectively.
- Natural frequencies determined by $\mathbf{E} \times \mathbf{B}$ flows, diamagnetic effects, and neoclassical effects.
- EPEC determines natural frequencies from experimental profile data (p-file). However, since there is no poloidal rotation data in NSTX, poloidal rotation is given its neoclassical value (including impurities and neutrals).

NSTX Shot 127317: Rutherford Island Equation Rhs



NSTX Shot 127317: Neoclassical Tearing Modes

- Previous figure shows that $m = 3$ and $m = 4$ modes are meta-stable NTMs.
- Both modes have potential to grow to large amplitudes ($W/a \sim 0.16$ and $W/a \sim 0.08$, respectively).
- No other $n = 1$ modes in plasma have Rutherford equation right-hand sides that rise above zero (i.e., they are all intrinsically stable).

NSTX Shot 127317: External Peturbation

- According to EPEC, if $n = 1$ simulation started in initial state in which all modes have very small amplitudes then mode amplitudes remain very small indefinitely. In other words, unperturbed plasma is stable.
- Apply external magnetic perturbation to system by applying square-wave $n = 1$ current pulse to RMP coils.
- Pulse has three properties:
  - Amplitude - kA.
  - Temporal extent (period) - ms.
  - Phase velocity - krad/s.
- How do these properties affect ability of pulse to trigger NTMs?