Effects of impurity injection-site asymmetries during disruption mitigation

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Abstract

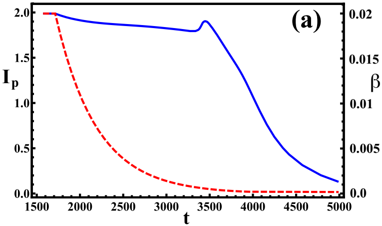
Thermal and magnetic energy content of the plasma have to be rapidly and uniformly removed during a disruption mitigation attempt so as to prevent damage to the plasma-facing components. Injection of high-Z impurities, either through massive gas injection at the plasma periphery (MGI), or by direct shattered pellet injection (SPI), aims to accomplish this goal by uniformly radiating away the plasma stored energy to the wall. However, due to geometric limitations on injection sites, nonuniformities in the radiation patterns and the resulting plasma response are inevitable. The goal of this work is to report on the preliminary results of a systematic numerical study of the effects of injection asymmetries on the expected radiation patterns and the generated magnetohydrodynamic (MHD) activity.

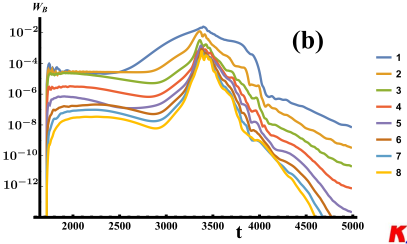
Introduction

- Initially certain simplifying assumptions are made, and ablation and ionization physics are not directly addressed.
- Instead the injected impurities are assumed to lead to a localized cooling of the plasma with a three dimensional Gaussian profile at one or more toroidal locations.
- The resulting nonlinear perturbation with $\delta p < 0$ propagates as a rarefaction wave, mostly in the parallel direction, forming well-defined cold flux tubes on nearby low-order rational surfaces.
- The initial dynamics of this expansion wave confirms the poloidal torque analysis presented earlier (Aydemir, PoP (2018)) and is consistent with the radiation patterns observed on DIII-D and elsewhere (Hollmann, PoP (2015), Eidietis, PoP (2017)).

An SPI example with single injector-I

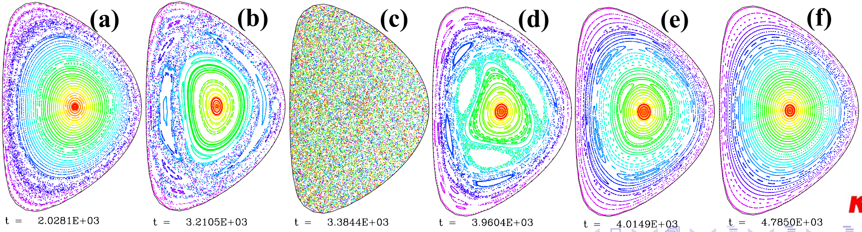
- Here we investigate two injection scenarios, with more examples and detailed analysis left for a future work.
- The first follows the nonlinear evolution of the plasma with three pellets at $r = 0, (r = 0.35, \theta = 1.2), (r = 0.7, \theta = 1.5)$, all at $\zeta = 0$.
- Resulting thermal and current quench profiles are shown in (a).
- The magnetic energy spectrum (b) shows that the nonlinear dynamics is dominated by an $n = 1$ mode that goes unstable first and is responsible for the induced disruption.





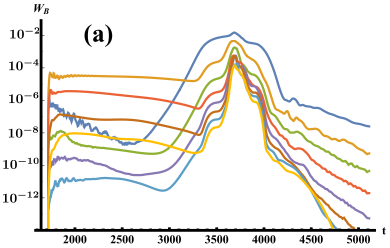
An SPI example with single injector-II

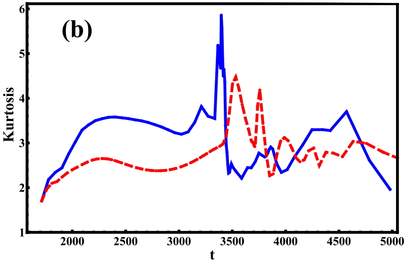
- The field becomes stochastic at the edge almost immediately due to interacting high m, n modes (a), but complete stochasticity is driven by a large $m = 2$ island and its satellites (b,c).
- Panels (d-f) show complete recovery of the flux surfaces during the current quench, with intermittent MHD activity, a behavior commonly observed despite variations in the injection conditions.
- Although RE physics is not included in these calculations, any runaway current generated during this period would tend to be well-confined, clearly an undesirable result.



Symmetric dual injections-I

- In the second, "dual-injector" scenario, in addition to the pellets of the first case, two more are injected at $(r = 0.35, \theta = 1.2)$ and $(r = 0.7, \theta = 1.5)$ but at $\zeta \approx \pi$.
- A separation of exactly π-radians is not used to avoid generating only even-numbered toroidal modes numerically.
- Individual pellet payloads are adjusted so that the total payload remains constant, resulting in TQ and CQ times similar to those of the earlier case.





Symmetric dual injections–Summary

- As seen in Panel (a) above, the magnetic energy spectrum for the dual-injection case is dominated by even-numbered toroidal mode numbers, $n = 2, 4, 6$, until the $n = 1$ goes unstable.
- During the disruption the spectrum is similar to that of the earlier single-injection case (page 4).
- In particular, $n = 1, 2$ are the dominant modes in both cases.
- We choose a kurtosis-like quantity defined over an annulus at the edge to characterize the degree of non-uniformity of the cooling effect, a higher value implying a more nonuniform distribution.
- As seen Panel (b) above, the double-injection case (dashed red curve) results in a much more uniform distribution of the injected cooling material.
- However, single and double-injections that penetrate near the core produce comparable results.

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