Non-linear MagnetohydroDynamic simulations of Edge Localised Mode triggering via Vertical Kicks with JOREK-STARRWALL

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1. Introduction

Magnetic triggering of Edge Localised Modes (ELMs) in tokamak plasmas was first reported in the TCV tokamak [1]. The experiments showed that imposing a vertical plasma oscillation using poloidal field coils (PF coils), leads to a reliable locking of the ELM frequency to the vertical oscillation frequency. These vertical oscillations often called “vertical kicks” were also used for ELM frequency control in the ITER-relevant type I ELM regime in ASDEX Upgrade [2] and DTF [3] tokamaks. This technique plays a crucial role to maintain the ELM frequency so that the ensuing ELM power fluxes remain within the operational limits of Plasma Facing Components and that ELMs provide the reduced impurity influx from the confined plasma.

2. Motivation

- Clarify the underlying physics of ELM triggering via vertical kicks
- Simulate for the first time vertical kicks and ELM triggering simulations in a single consistent scheme
- Vertical kicks are also considered as a back-up ELM control technique in ITER [5] at low current H-mode operation.

3. Physics model and numerics

3.1 Plasma Model

- Reduced MHD in toroidal geometry
- Radiation
- C1 Finite Element Method in the poloidal plane (Bessel Elements) [9]
- Fourier decomposition in the toroidal direction
- Fully implicit time discretisation (Crank Nicolson / Gear scheme)
- Free-boundary extension: including 3D coils and passive structures and their mutual interactions explicitly.

3.2 NUMERICAL CODE: JOREK-STARRWALL presents the following features

- 3D toroidal geometry
- Non-linearity
- C1 Finite Element Method in the poloidal plane (Bessel Elements) [9]
- Fourier decomposition in the toroidal direction
- Fully implicit time discretisation (Crank Nicolson / Gear scheme)
- Free-boundary extension: including 3D coils and passive structures and their mutual interactions explicitly.

4. Benchmarking JOREK-STARRWALL

- Benchmark of a vertical kick on an ITER J7.5MA/2.65T scenario with DNA [6]
- Time varying coil currents and passive structures were implemented
- Mutual interaction between coils and walls were necessary for good agreement

5. Understanding edge current induction during kicks

- The induced edge current during the vertical motion was proposed as mechanism for ELM triggering [3,4]
- A simple cylindrical model reveals that the induced edge current $I_{Ed}$ is due to
  1. A change in the boundary external flux $\Delta \Phi_b (\rho)$
  2. Edge plasma compression $\Delta \rho$:
  $I_{Ed} = \frac{4 \pi}{\mu_0} \mu \rho \frac{\partial \Phi_b}{\partial \rho}$
  3. Dependence on velocity ($\rho_t$) only in the relative time term
- Realistic ITER kick simulations reveal
  1. Maximum induced current is related to maximum plasma compression
  2. Compression is due to the plasma motion through the inhomogeneous magnetic field of the PF coils
  3. Optimization of the current waveforms of the coils used to oscillate plasma position can be used to enhance compression

6. Simulations of ELM destabilization

- Downward kicks are able to destabilize the n = 6 mode with a (peeling) ballooning structure
- Initially unstable plasmas can be further destabilized by a downward kick and stabilised by an upward one

7. Conclusions

- The induced edge current during a kick is due to the plasma motion through an inhomogeneous magnetic field. The induction of current can be further improved by enhancing the plasma compression with different configurations for the coils used for plasma vertical oscillations
- ELM-like modes were destabilized with downward kicks and stabilized with upward kicks
- As in experiments, ELMs are destabilized at the same vertical displacement $\Delta Z_{ELM}$ regardless of the plasma velocity
- The required $\Delta Z_{ELM}$ to destabilize an ELM strongly depends on the initial current profile. This suggests that the induced current during the kick is the main factor for ELM destabilization

8. References


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