MHD Induced Fast-Ion Losses in ASDEX Upgrade

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• Scintillator detector design based on:

• The strike points of the ions on the scintillator plate depend on their gyroradius and pitch angle (~magnetic spectrometer)
Fast-ion losses due to NTMs; NBI ions

Typical FIL pattern in pure NBI-heated discharges with NTM activity

(2,1) NTM contribution to fast-ion losses:

- Enhancement of the NBI prompt loss patterns
- Fast-ion losses in a phase-space area corresponding to passing orbits

NBI modulated experiments to study fast-ion loss time scales

Correlation between FIL, (2,1) magnetic perturbation and NBI source modulation

(a) magnetic pick-up coil - #21168

(b) FILD ch # 7 - #21168
NBI modulated experiments to study fast-ion loss time scales
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Fast-ion loss mechanisms; time scales

Modelling results in good agreement with measurements


Fast-ion loss signal on passing orbits decay within μs

Fast-ion loss signal on trapped orbits decay within ms

S. Guenter, TH/P9-10
Fast-ion loss mechanisms; time scales

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Fast-ion losses due to NTMs; ICRF ions

(3,2) NTM induces ICRF fast-ion losses in improve H-mode discharges

Loss pattern shows NBI prompt losses and ICRF lost ions due to NTM

- NTM losses appear in the trapped domain → \( \arccos \left( \frac{v_{\|}}{v} \right) = 60^\circ - 70^\circ \)
- Gyroradius \( \approx 50 \) mm corresponding to hydrogen ions with \( E = 600 \) keV

NTM magnetic fluctuation and FIL correlation

Clear correlation in frequency, phase and amplitude

• Maximum losses appear between O-point and X-point of magnetic island
• Signal decay at constant island width →
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Fast-Ion Losses due to Fast-Ion Driven MHD Instabilities

On ASDEX Upgrade:

- ICRF heated discharges
- Multiple fast-ion driven MHD instabilities observed using magnetic pick-up coils
- A new core localised non-alfvenic instability "Sierpes mode" has been identified by SXR diagnostic
- Including background diamagnetic effects, a reasonable agreement has been found between $f_{Sierpes}$ and $f_{BAE}$ when the FI pressure is not too large (i.e. rapid $f$-rise before sawtooth crash or $f$-chirping)

Observation of ICRH Fast Ion Losses due to Fast Ion Driven MHD Instabilities

Selective character of the loss mechanisms; ICRH tail ions lost with two different energies ($I_p = 1.2$ MA, $B_t = 2$T)

- Gyroradii corresponding to hydrogen ions with $E = 300$ keV and $E = 600-1600$ keV
- Correlation in frequency and phase with fast-ion driven MHD fluctuations (TAEs and Sierpes)
Fast-ion loss rates due to TAEs and Sierpes

Analysis of the fast-ion loss evolution tracking the Sierpes and TAE frequencies

• The Sierpes mode always seems to be more effective ejecting ions than the individual TAEs

• A correlation between the spikes of the fast-ion losses due to Sierpes and TAEs suggests a coupling between fast-ion loss mechanisms
Loss mechanisms coupling; particle channeling

TAEs and Sierpes radial eigenfunction reconstructed with the MHD-IC code and their SXR emissions

\[ \rho_{pol} \]

\( (n=4,m=4) \)

Sierpes

\( (n=4,m=4,5) \)

TAE

TAEs and Sierpes radial eigenfunction reconstructed by the MHD-IC code and their SXR emissions

- Fast ions pressure profile calculated by the PION code reveals high local FI pressure and gradients at the Sierpes and TAE locations
- The radial chain of FI driven MHD fluctuations may explain the higher FI transport towards the vessel wall
- A transient overlapping of the Sierpes and TAE eigenfunction may enhance drastically the FILs

Internal MHD fluctuations must be taken into account in order to reproduce quantitatively the FI transport due to FI driven MHD instabilities

TAE and Sierpes loss mechanisms; numerical simulations

- Initial FI distribution function for HAGIS based on results obtained by the ICRH modeling codes PION and FIDO
  - Central localization of the maximum fast ion pressure within $\rho \sim 0.25$. $E_\parallel < 10\%$ $E_{\text{tot}}$, $\beta_{\text{fast}} \sim 25\% \beta_{\text{tot}}$

- Orbit properties investigated using HAGIS code. On-axis ICRF minority heating
  - Distribution function described by $\Lambda = \mu B_0 / E = 1 \& fW \sim \exp(-E/T)$
  - Trapped orbits with turning points at ICRH resonance layer ($v_{\parallel} = 0$ at magnetic axis):
    \[ P_\phi = mR v_{\parallel} - e\psi \rightarrow z \leftrightarrow \psi = -P_\phi \]
  - $\omega_\phi \in (0,250)$ $\omega_\theta \in (0,500)$ kHz with $E$ up to 1.6 MeV

M. J. Mantsinen et al., RF Topical (2007)
Resonant ICRH ions

General resonance condition: $\Omega_{np} = n \omega_\phi - p \omega_\theta - \omega_{\text{MHD}}$

- Linear simulation without considering MHD perturbation amplitude

- An energy/canonical momentum exchange takes place if the resonance conditions are fulfilled by the typical fast-ion orbital and wave frequencies

- A quantitative analysis of the losses required non-linear simulations of the interplay evolution between fast-ions and eigenmodes
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Resonant ICRH ions

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Log (1/\(\Omega_{np}\)) TAE n=5
Log (1/\(\Omega_{np}\)) Sierpes mode n=4

Unconfined Orbits

Energy (MeV)

M. García-Muñoz, IAEA 2008, Geneva, Switzerland
• A fast-ion channeling in phase space might be being the responsible for the coupling between TAE and Sierpes loss mechanisms

• An overlapping of resonance conditions (i.e. \( p=1 \)) might increase strongly the fast-ion loss fluxes
## Summary

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Sierpes mode nature

At moderate fast-ion pressures, Sierpes mode follows BAE dispersion relation

\[ \omega_{BAE}^2 = \frac{v_{thl}^2}{R_0^2} \left[ \frac{7}{4} + \tau (1 + \frac{1}{2q^2}) \right] \]

Hybrid mode. Coupling with the Kinetic ballooning Branch explains also the frequency rise

M. García-Muñoz, IAEA 2008, Geneva, Switzerland
1) NBI well confined passing ion losses due to NTMs. Drift Islands

2) ICRH trapped ion losses due to NTMs and TAEs. Phase matching. Convective mechanism. ($\sim \delta B_r$)

3) NBI trapped ion losses due to NTMs. Diffusive transport. Orbit stochasticity

4) A new core-localised non-Alfvenic MHD perturbation. *Sierpes Mode*. It dominates the FI transport in ICRH discharges