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Profile effects on the dissipation of runaway beams by impurity injection in tokamak disruptions

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MOTIVATION

- Two layers of defense have been proposed for runaway electron (RE) mitigation during disruptions [1]:
  - (1) Preventing the generation of MA RE currents (RE avoidance)
  - (2) Mitigating the wall impact of the RE beam by Shattered Pellet Injection (SPI) in case that its formation cannot be avoided

Aim: evaluation of profile effects on the dissipation of RE beams by impurity injection

MODEL EQUATIONS

1D model (cylindrical geometry)

One dimensional (1D) modeling including the evolution of the plasma current and RE current density profiles [2]

current diffusion

$$\mu_0 \frac{\partial j_p}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left[r\frac{\partial E_\parallel}{\partial r}\right]$$

electric field

$$E_\parallel = \eta\left(j_p - j_r\right)$$

RE current dissipation [3]

$$\frac{\partial j_r}{\partial t} \approx \frac{ec\left(E_\parallel - E_R\right)}{T_r} j_r$$

T_r: characteristic energy decay of the initial RE energy distribution

$$E_R \approx \frac{e^3 \alpha_e}{4\pi \varepsilon_0^2 m_e c^2}$$ [2]

$$\alpha_e \equiv n_{ef} \ln\Lambda_{ef} + n_{eb}\ln\Lambda_{eb}$$

- n_{ef}, n_{eb}: free and bound electron densities
- $\ln\Lambda_{ef}$, $\ln\Lambda_{eb}$: Coulomb logartihns for the collisions of the REs with the free and bound electrons

RE kinetic energy dissipated per unit volume

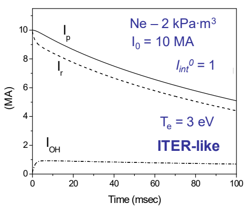
$$\Delta w_{run} = \int dt'\, j_r \left(E_\parallel - E_R\right) = \frac{T_r}{ec}\left(j_r - j_r^0\right)$$

Total dissipated RE kinetic energy

$$\Delta W_{run} = \int dv\, \Delta w_{run} = \frac{2\pi R_0 T_r}{ec}\left(I_r - I_r^0\right)$$

CURRENT PROFILE SHAPE EFFECTS

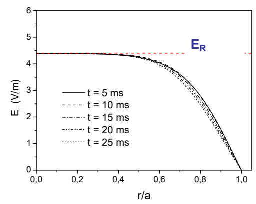
- RE current generated during disruptions is expected to be more peaked in plasma center than the pre-disruption plasma current
- This peaking of the current can have important consequences on the RE dissipation by impurity injection



(uniform impurity deposition)

When the impurities are injected, the dissipation of the RE current occurs

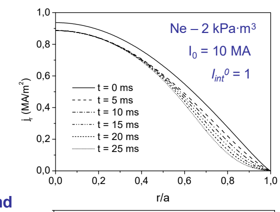
(*** In ITER, 1 kPa·m³ ~ 2.5 x 10[23] atoms)

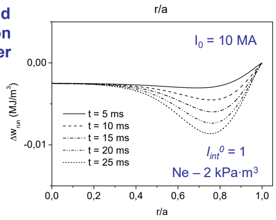


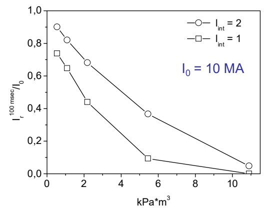
due to the central peaking of the current, the induced $E_\parallel$ increases close to E_R in the plasma center

...and is far from E_R in the outer plasma

the drop of the current and the energy dissipation mostly occurs in the outer plasma region



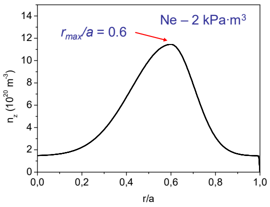


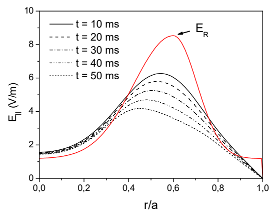


The dissipation efficiency decreases when the initial RE current peaking increases

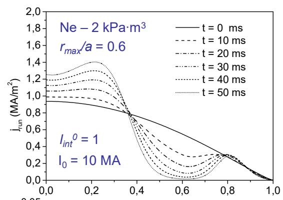
NON-UNIFORM IMPURITY DEPOSITION

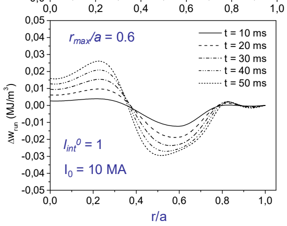
Radially localized impurity deposition profiles are expected during impurity injection



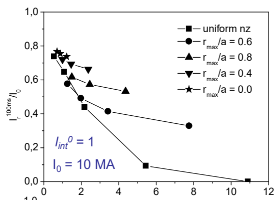


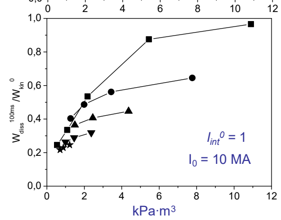
- **Localized impurity deposition**
  - **induced electric field lower than E_R in the main deposition region** → **current and energy dissipation**
  - **inward diffusion of $E_\parallel$** → **current density increase and energy transfer**





overall non-uniform impurity deposition reduces the dissipation efficiency





- **the most efficient dissipation is found for radially uniform impurity deposition**
- **the dissipation efficiency decreases for too inner or too outer deposition**

REFERENCES

[1] REUX, C., et al., *Plasma Phys. Control. Fusion* **64**, 034002 (2022)
[2] MARTIN-SOLIS, J.R., et al., *Nucl. Fusion* **57**, 066025 (2017)
[3] MARTIN-SOLIS, J.R., in Fusion Energy 2018 (Proc. 27th Int. Conf., Ahmedabad 2018 (Vienna: IAEA) CD-ROM file TH/P4-1

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