Current profile shape effects on the formation and termination of runaway beams during tokamak disruptions and implications for ITER

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MOTIVATION

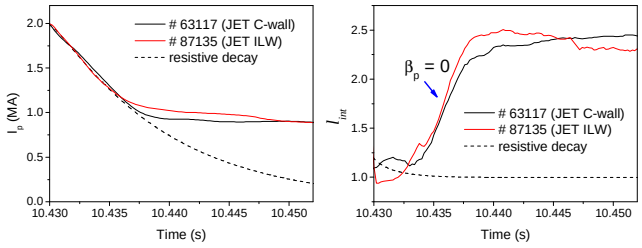
• Large runaway (RE) currents can be generated during the current quench (CQ) phase of disruptions in ITER

• Substantial peaking of the current profile during the generation of the RE current is predicted by one-dimensional (1-D) modeling of the plasma and RE current density profiles during the disruption current quench [1]

Aim: analysis of effects associated with the plasma and RE current profile evolution during the disruption CQ and termination and consequences for the formation and termination of the RE beam

CURRENT PROFILE SHAPE EFFECTS DURING RUNAWAY ELECTRON PLATEAU FORMATION IN JET DISRUPTIONS

Peaking of the current profile during generation of the RE current is supported by the observed increase of the plasma internal inductance (l_{int}) in JET disruptions with current plateau formation



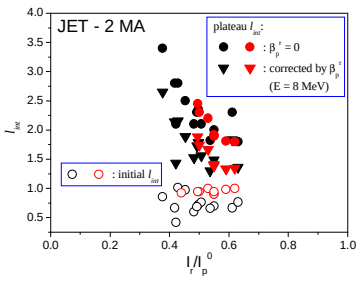
l_{int} estimated by means of plasma equilibrium reconstruction with EFIT

Shafranov Λ → $l_{int} = 2\,(\Lambda - \beta_p^r)$

β_p^r: poloidal beta of the runaways: $\beta_p^r \approx \gamma \frac{I_{A0}}{I_r}$

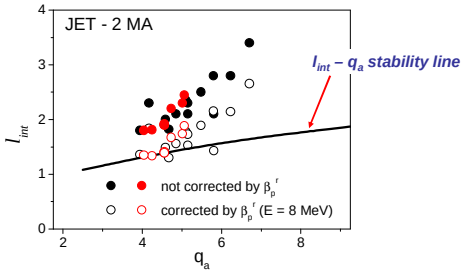
($I_{A0} \approx 17$ kA; runaway energy: $E = (\gamma - 1)\, m_e c^2$)

JET C- wall (black) and ILW (red) disruptions



- RE plateau current is always more peaked than the initial (at the start of the CQ) current
- the peaking (l_{int}) of the RE current decreases with the RE current fraction in agreement with theoretical expectations [2]

the observed peaking suggests potentially RE MHD unstable plasmas



MODELING OF RE FORMATION AND TERMINATION IN ITER DISRUPTIONS

1D modeling, including current profile shape effects, has been carried out for ITER disruptions with Ar and Ne injection before the thermal quench (TQ)

1D model (cylindrical geometry)

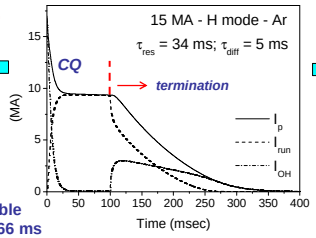
$$\mu_0 \frac{\partial j_\parallel}{\partial t} = \nabla^2 E_\parallel \quad \leftarrow \textit{current decay}$$

$$E_\parallel = \eta (j_p - j_r) \quad \leftarrow \textit{electric field}$$

$$\frac{\partial j_r}{\partial t} = \left(\frac{\partial j_r}{\partial t}\right)_{primary} + \left(\frac{\partial I_r}{\partial t}\right)_{secondary} - \frac{j_r}{\tau_{diff}} \quad \leftarrow \textit{runaway generation and loss}$$

Runaway beam formation (disruption CQ)

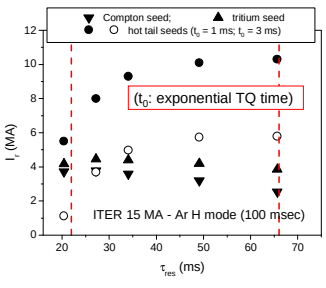
- primary runaway sources
- RE avalanche
- collisions of REs with partially stripped impurity ions (free and bound electrons)
- no runaway losses ($\tau_{diff} \rightarrow \infty$)
- τ_{res} must be consistent with acceptable mechanical forces in ITER (τ_{res} ~ 22-66 ms for 15 MA disruptions [3])

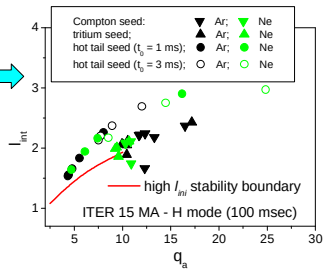


Disruption termination

- the termination phase starts at the expected time in ITER for the vertical instability growth (~ 100 ms) [4]
- τ_{diff} = 0.1 – 10 ms in agreement with observations in actual devices

Predicted runaway current (100 ms)



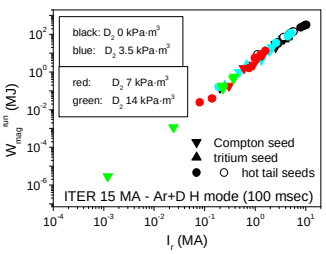


significant RE currents (~ 10 MAs) for the longest CQs

the RE beam typically crosses the high-l_{int} empirical stability boundary before 100 ms

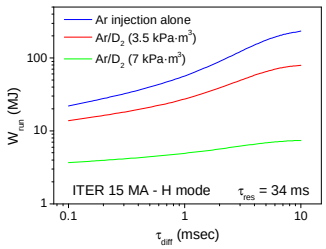
Mixed Ar+D / Ne+D injection

Mixed Ar+D or Ne+D injection is found to be effective in controlling the formation of the RE current as well as the energy deposited by the REs onto the Plasma Facing Components (PFCs)



for 14 kPa·m^3 D_2 injection, the magnetic energy of the RE beam (W_{mag}^{run}) is less than 1 MJ

Energy deposited by the REs during current termination onto PFCs



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