RUNAWAY ELECTRON AVALANCHE AND ENERGY DEPOSITION DURING SCRAPING-OFF OF VERTICALLY UNSTABLE DISRUPTION GENERATED RUNAWAY BEAMS

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Large MA runaway (RE) currents can be generated during the current quench (CQ) of tokamak disruptions, mainly due to the avalanche mechanism, which, in case of interacting with the first wall structures could lead to serious damage, demanding for the development of efficient mitigation schemes for the disruption generated runaways. The benign termination of RE beams by injection of low-Z impurities [1,2] leading to the deconfinement of the REs without conversion of magnetic into RE kinetic energy, is being actually considered as a promising runaway mitigation scheme.

In this work, the fast deconfinement of the runaway current during disruptions is investigated, focusing on the conversion of magnetic into RE kinetic energy during the termination of the current. In the past, the termination of vertically stable RE beams was considered [3,4]. However, in ITER, the RE current is expected to be vertically unstable and, hence, the scraping-off of the beam when the plasma touches the wall can result in a large enhancement of the electric field, runaway avalanche and energy deposition on the plasma facing components (PFCs). Here, the effect of the scraping-off of vertically unstable plasmas during fast deconfinement of disruption generated REs is analyzed using a 0D three loop model for the plasma current and the currents in the wall [5,6]. It is found that the drop of the RE current during deconfinement leads to the acceleration of the plasma and to a large increase of the electric field when it hits the wall during scraping-off, yielding a substantial RE avalanche which can result in the recovery of the runaway current and a noticeable increase in the amount of energy transferred to the RE population. The energy deposited on the runaways, ΔW_{run}, increases with the characteristic RE deconfinement time, τ_d, and a reduction of ΔW_{run} to low enough values in ITER (~ few MJs) requires a short enough τ_d, below 0.5 ms for low T_e (~few eVs) (left Fig.1) and, in that case, recovery of RE current does not occur. Also, ΔW_{run} decreases when the resistive decay time of the residual ohmic plasma, τ_{res}, increases, due to the larger induced ohmic current, so that, overall, the energy transferred to the REs increases with τ_d/τ_{res} (right Fig.1).

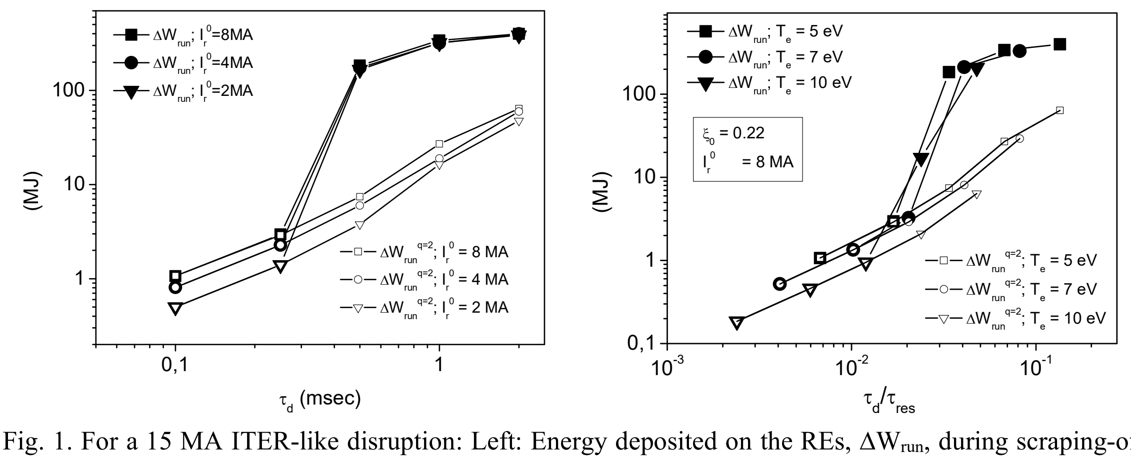

Fig. 1. For a 15 MA ITER-like disruption: Left: Energy deposited on the REs, ΔW_{run}, during scraping-off vs τ_d for three different values of the RE current at deconfinement (I_r^0 = 2, 4, 8 MA); Right: ΔW_{run} vs τ_d/τ_{res} (I_r^0 = 8 MA). The normalized (to the wall radius) vertical position at deconfinement is ξ_0 = 0.22, T_e = 5 eV, and $n_e = 10^{22}$ m^{-3}. The open symbols correspond to the energy deposited until the edge safety factor q_a = 2 is reached, $\Delta W_{run}^{q=2}$.

The conversion of magnetic energy into runaway energy is larger when the deconfinement starts closer to the wall or during the scraping-off phase, but the effect is not strong unless it takes place well inside the scraping-off.

Another common feature of disruptions is magnetic stochasticity. It has been suggested that stochastic magnetic fields, both during the thermal and current quench of the disruption, leading to RE losses, can have an important effect on the final RE current and, so, on the potential RE damage on the PFCs [7]. Here, the effect of magnetic stochasticity during the disruption CQ of vertically unstable RE beams has been analyzed using the 0D three loop model [6], aiming to the investigation of the conditions to avoid a large RE energy deposition on the PFCs during the scraping-off of the beam. Strong losses (low characteristic RE loss time, τ_d) and a sufficiently long stochastic period (τ) are needed to control the PFC damage. For given values of (τ,τ_d), the RE current at the time the plasma contacts the wall (I_r^c) and the energy transferred to the REs during scraping-off decrease when τ/τ_d increases, unless the plasma hits the wall during the stochastic period (contact time $t_c < \tau$) leading to saturation for $\tau > t_c$ (Fig.2). Thus, it is obtained that, for low temperatures (~ few eVs) of the residual ohmic plasma during the disruption in ITER, $\tau_d < 1$ ms and $\tau/\tau_d > 5$ would be required to reduce ΔW_{run} to a few MJs or below. Moreover, independently of the model used for the magnetic stochasticity and the runaway losses, it is found that the relevant parameter determining the energy deposited on the runaway electrons during scraping-off is the RE current at the time the plasma hits the wall, I_r^c, and this study suggests that I_r^c should be kept quite low, in a range ~few kAs to tens of kAs. The role played by the primary RE seeds after the stochastic phase, once the flux surfaces reform, is also analyzed.

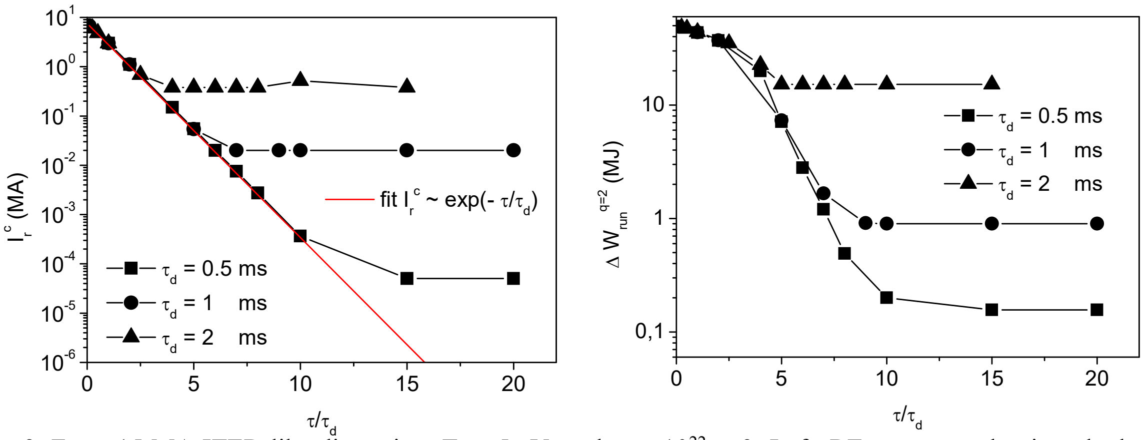

Fig. 2. For a 15 MA ITER-like disruption, $T_e = 5$ eV, and $n_e = 10^{22}$ m-3: Left: RE current at the time the beam contacts the wall, I_r^c, vs τ/τ_d (in red an exponential fit to τ/τ_d); Right: $\Delta W_{run}^{q=2}$ vs τ/τ_d (squares: $\tau_d = 0.5$ ms; circles: $\tau_d = 1$ ms; triangles: $\tau_d = 2$ ms).

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