Mitigation of disruption-generated runaways by means of ECRH

B. Esposito[1], G. Granucci[2], S. Nowak[2], S. Vitulli[1], J.R. Martin-Solis[3],
M. Leigheb[1], L. Gabellieri[1], F. Gandini[2], F. Iannone[1], D. Marocco[1],
C. Mazzotta[1], A. Pensa[1], R. Sanchez[3], P. Smeulders[1]
[1]*Associazione Euratom-ENEA sulla Fusione, CR Frascati, C.P. 65, 00044 Frascati, Italy*
[2]*Associazione Euratom-CNR sulla Fusione, IFP-CNR, Via R. Cozzi 53, 20125 Milano, Italy*
[3]*Universidad Carlos III de Madrid, Avenida de la Universidad 30, 28911 Madrid, Spain*

Introduction

When a population of runaway electrons is present in the plasma current plateau phase of FTU discharges, it is found experimentally that, during electron cyclotron resonance heating (ECRH), the runaway energy decreases and the whole runaway population is often quenched. An analysis of the runaway dynamics based on a test particle model, including acceleration in the electric field, collision with the plasma particles and synchrotron radiation losses, has shown that the cause of such runaway suppression is a drop of the plasma resistivity (and in turn of the toroidal electric field) due to ECRH heating [1]. In order to evaluate the suitability of this scheme for the mitigation of disruption-generated runaways, experiments have been carried out in FTU in which ECRH power has been applied during controlled disruptions triggered a) by injection of Mo through laser blow-off (LBO) and b) by puffing deuterium gas until the density limit is reached. The main objective of the experiment is to verify whether the application of ECRH is capable of reducing the number/energy of runaways generated at the disruption. A by-product of the experiment is the possibility of avoidance of the disruptions.

Experiments

The experiments have been carried out at $B_t = 5.3$ T. The EC power (140 GHz, up to 1.6 MW delivered by 4 gyrotrons [2]) has been injected both with on-axis and off-axis absorption (varying toroidal injection angle (0 and 30 degrees) or steering the launching mirrors along the z-axis). The ECRH pulses (with pre-programmed duration in the range 30-95 ms) have been started using as a trigger the V_{loop} signal exceeding a preset threshold (usually $V_{thr} = 3.5$ V). Such feedback system, based on an electronic comparator, has proved to be very reliable in allowing the start of the ECRH pulse always before the collapse of the plasma current. Up to three ECRH gyrotrons have been used, each gyrotron delivering about 0.4 MW to the plasma. The disruptions were obtained by firing Mo into the plasma at t=0.8 s in 500 kA discharges (the disruption occurring within 50 ms after the injection of Mo) or by preprogramming $\bar{n}_e$ above the density limit (~1.2×10^{20}m^{-3}) in 360 kA discharges. Usually, one or two spikes of γ-ray emission due to runaways, as measured by a NE213 scintillator working in current mode, are observed at the disruptions in correspondence with negative spikes in the V_{loop} signal (**Fig.1**). The energy of these γ-rays can be measured by a NE213 spectrometer system with digital acquisition at 200 MSamples/s and n/γ discrimination of pulses [3].

Results

The γ-ray spectra in the time windows corresponding to the runaway spikes at the disruption indicate a maximum of ~5 MeV photon energy (both with and without applied ECRH): this is consistent with the fact that photoneutrons (which can be produced when the runaway energy exceeds the threshold for photonuclear reactions in the limiter materials, i.e. > 7 MeV [4]) were not observed in these disruptions. In few disruptions (in which, unfortunately, no spectra were available) photoneutrons were indeed observed, but some runaways were already present in these cases from the early phase of the discharge, as in such phase the BF_3 chambers (neutrons) and NE213 scintillator (neutrons and γ-rays) time traces do not overlap [5]. The integral of the γ-ray spikes from the NE213 scintillator current signal plotted versus injected ECRH power for all triggered disruptions is shown in **Fig.2**. Two facts can be deduced: 1) the level of the γ-ray spikes is higher when runaways were already present before the disruption; 2) some reduction of the number of runaways (assuming roughly the same runaway energy distribution in all disruptions) is obtained when ECRH is used at the disruption, especially at high power (> 0.8 MW) when some pre-disruption runaways are present (white squares): this runaway suppression effect may be similar to that observed in [1]. Some features at the disruption are different depending on how the disruption is obtained. When the disruption is triggered by injection of Mo by LBO the current decay may be lengthened with ECRH (**Fig.3**), as was already observed in RTP [6]. Moreover, the disruption may even be prevented and this was found to occur reproducibly (same result in three subsequent discharges) when ECRH is applied off-axis at z=18 cm (**Fig.4**): calculations of the ECRH power deposition in this case (discharge #27797) indicate that the absorption location is indeed at r/a ~0.6 and the fraction of absorbed power is around 30% (corresponding to ~ 0.4 MW). Larger fractions of absorbed power are obtained, as expected, with more central ECRH deposition (**Fig.5**), but in these cases the disruption triggered by injection of Mo is not avoided. When the disruption is triggered by exceeding the density limit, the observed I_p decay is long and avoidance of the disruption can be obtained by on-axis ECRH: no γ-ray spikes are observed during the ECRH pulse (**Fig.6**); in these discharges the use of ECRH, allows the plasma to reach a density higher than the Greenwald limit (above 2×10^{20} m^{-3} at 360 kA), although in unstable conditions (oscillations in density, temperature and neutron rate).

Conclusions

Avoidance of disruptions and/or reduction of the runaway emission by applying ECRH has been shown in FTU controlled disruptions. The optimum location of the ECRH power deposition seems to depend on the type of disruption: those triggered by Mo injection were mainly avoided with off-axis deposition, while those triggered by density limits (soft disruptions) with on-axis deposition. The necessary minimum absorbed ECRH power was ~40% of the ohmic power in both cases. The level of γ-ray spikes detected at the disruption is found to be higher when a “seed” of runaways is already present in the early phase of the discharge before the disruption. Although there are indications of a decrease in runaway emission when ECRH is applied at the disruption, further analysis is needed to establish whether the underlying mechanism of runaway suppression is the same as described in [1].

Acknowledgements

We thank the FTU and ECRH teams for the machine and ECRH system operation.

References

[1] J.R. Martin-Solis et al., Nucl. Fusion **44** (2004) 974
[2] M. Aquilini et al., *Fus. Sc. and Technology* **45** (2004) 459-482
[3] B. Esposito et al., Nucl. Instr. Meth. **A518** (2004) 626
[4] G. Maddaluno and B. Esposito, Journ. Nucl. Mat. **266-269** (1999) 593
[5] B. Esposito et al., Phys. Plasmas, **10** (2003) 2350
[6] F. Salzedas et al., Nucl. Fusion **42** (2003) 881

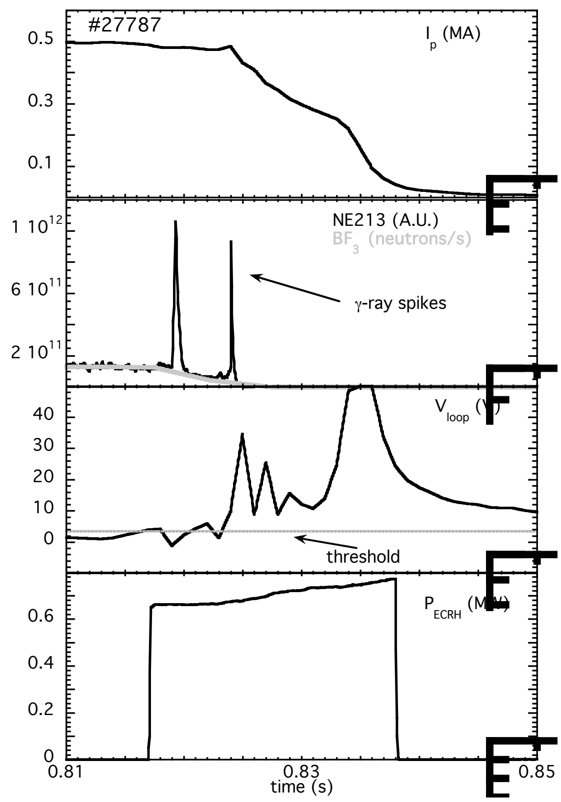

Fig.1: Spikes on γ-ray emission and V_{loop}: the ECRH pulse is triggered when V_{loop} exceeds 3.5 V.

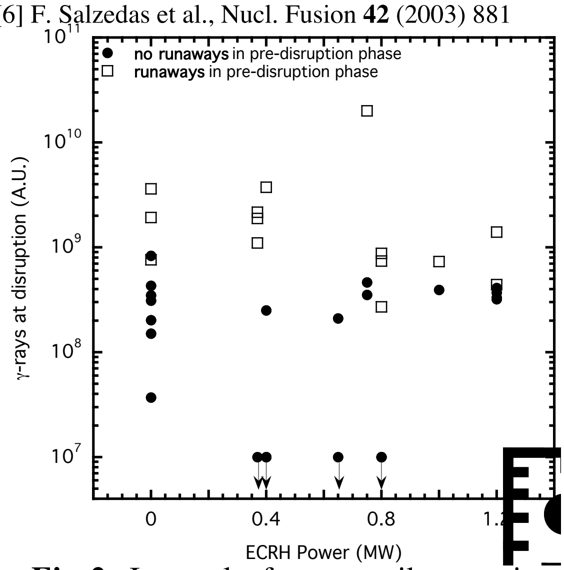

Fig.2: Integral of γ-ray spikes at time of triggered disruptions vs. injected P_{ECRH} (points with arrows are below detectability).

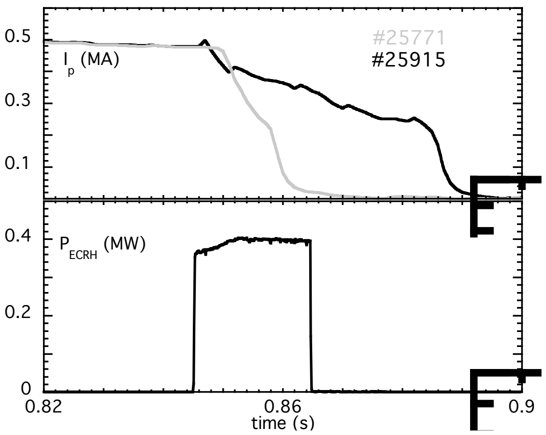

Fig.3: Disruptions by injection of Mo: softened I_p decay in #25915 (with on-axis ECRH) and normal I_p decay in #25771 (no ECRH).

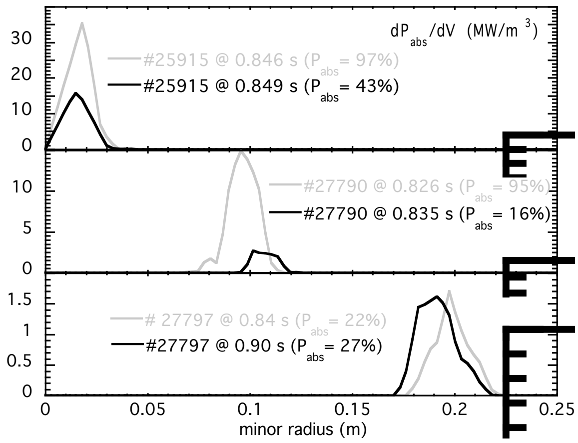

Fig.5: P_{ECRH} deposition profiles for Mo injection disruptions (grey: pre-disruption; black: post-disruption trigger); P_{ECRH}= 0.4 MW (#25915), 1.0 MW (#27790), 1.2 MW (#27797).

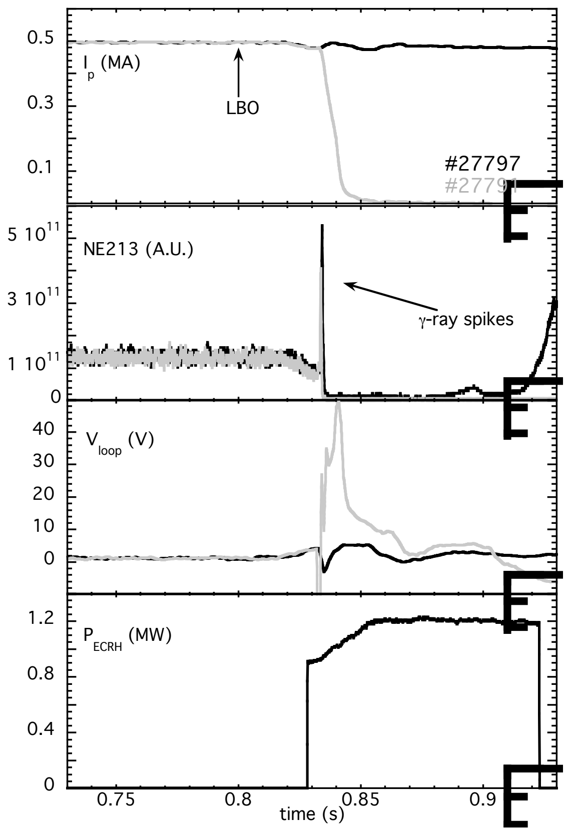

Fig.4: Disruptions by injection of Mo: time traces of I_p, γ-rays, V_{loop}, P_{ECRH} in 27797 (with z = 18 cm off-axis ECRH) and in #27791 (no ECRH).

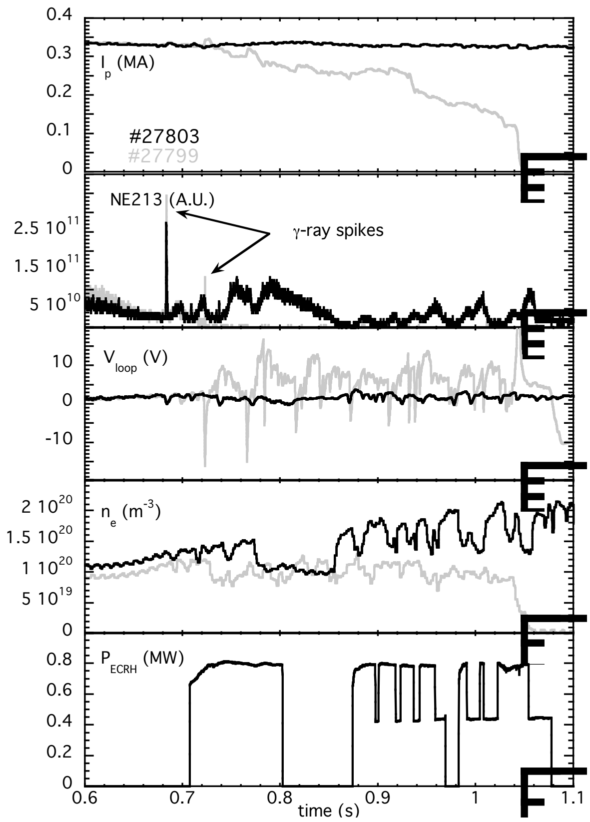

Fig.6: Disruptions by exceeding the density limit: time traces of I_p, neutrons and γ-rays, V_{loop}, $\bar{n}_e$, P_{ECRH} in #27803 (with on-axis ECRH) and #27799 (no ECRH).