View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Ghent University Academic Bibliography

Effects of Plasma Control on Runaway Electrons in the COMPASS Tokamak

J. Mlynar[1], O. Ficker[1,2], M. Vlainic[1,3], V. Weinzettl[1], M. Imrisek[1,4], R. Paprok[1,4], M. Rabinski[5], M. Jakubowski[5] , M. Tomes[1,4], M. Peterka[1,4], R. Panek[1] and the COMPASS Team

[1]*Institute of Plasma Physics AS CR, Prague, Czech Republic*

[2]*Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Czech Republic*

[3]*Department of Applied Physics, Ghent University, Ghent, Belgium*

[4]*Charles University in Prague, Faculty of Mathematics and Physics, Prague, Czech Republic*

[5] *National Centre for Nuclear Research (NCBJ), Otwock-Swierk, Poland*

1. Introduction

Runaway Electron (RE) mitigation after disruptions presents one of the key challenges for safe operation of future fusion reactors. In support of related research efforts (see e.g. [1]-[7]) systematic studies of RE generation and losses in the COMPASS tokamak started in early 2014 in the Framework of the EUROfusion WP14-MST2-9 research project. The COMPASS tokamak features ITER-relevant geometry with $R = 0.56$ m, $a = 0.23$ m, $I_p < 400$ kA, $B_T \sim 1.15$ T, up to 2x 350 kW of Neutral Beam Heating and typical pulse length around 300ms. It can operate with inner limiter or single null (divertor) plasma configuration. In the latter case, routine operation in the H-mode was achieved. Plasma edge studies and the related diagnostic development are in the main focus of the COMPASS research team [8]. The RE research relevant diagnostics is rather sparse at present (see Fig. 1), however, it has been extended in collaboration with the NCBJ Poland (development of the Cherenkov detector) and the Czech Technical University (NaI(Tl) detector, MediPix pinhole camera), while further investments are foreseen (e.g. the neutron detector). The hard X-ray (HXR) scintillation detectors present the key diagnostic tool in this work. These detectors measure non-collimated radiation that originates mostly from RE collisions with the tokamak inner wall

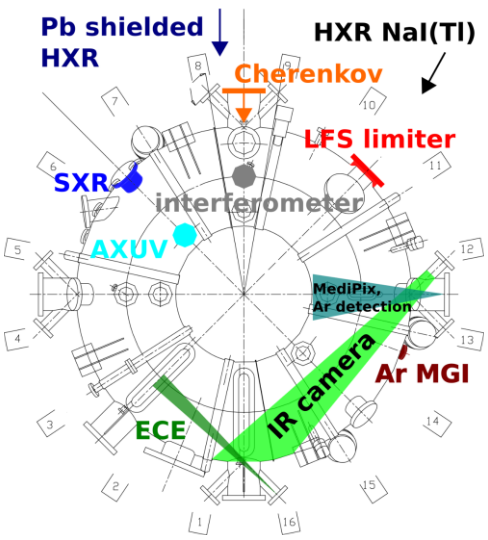

Figure 1. Setup of the diagnostic systems for the RE studies at COMPASS tokamak.

(bremsstrahlung and deexcitation in solid components). One HXR detector is located outside the tokamak so that its threshold for the HXR energy is above 50 keV. The second HXR detector is at a similar distance from the tokamak, however it is shielded by 10 cm Pb box; its lower energy threshold is therefore well above 500 keV. In the RE dominated COMPASS discharges, the RE generated synchrotron radiation was directly measured by infrared camera, see [9]. These observations indicate that the maximum energy of the Runaway Electrons (REs) is around 25 MeV. RE beams after argon triggered plasma disruptions were successfully observed in the current ramp-up phase of the COMPASS plasma discharge, which opened new prospects for ITER-relevant studies on RE control and mitigation at COMPASS [10]. In this contribution, it is demonstrated that the RE seed production during plasma breakdown plays a key role in formation of the RE population observed in the current plateau and current ramp-down of the discharge. Next, the observed dependences of the RE confinement on plasma shaping and plasma current are presented.

2. Plasma deuterium fuelling and generation of the Runaway Electrons

Experiments with plasma fuelling were aimed at improving our understanding of the impact of the initial (seed) RE generation on the overall properties of REs in the subsequent current plateau phase of the discharge. The results are also applicable to other COMPASS research programmes where the early RE mitigation may improve plasma parameters and/or diagnostic performance. In the experiments, the plasma border was defined by high-field side limiter and plasma density was feedback controlled in the current plateau at a level far from the RE dominated discharges in order to minimise RE production in the plateau phase. First, discharges with circular cross-sections and plasma density $n_e \sim 3.1 \cdot 10^{19}$ m^{-3} were studied, see Fig. 2a. It can be seen that a single initial puff of fuel at plasma breakdown resulted in generation of an intense RE population, which is due to high U_{loop} and low density in the current ramp-up phase. In the discharge plateau, however, REs got mitigated in a relatively high plasma density; this process is witnessed by the exponential decrease of the HXR radiation. Under the same conditions, a secondary fuel puff during the early current ramp-up completely mitigated the RE seed and, consequently, no HXR radiation was observed. In either case the Pb shielded HXR detector registered no useful signal. Second, discharges with elongated plasmas and density $n_e \sim 2.5 \cdot 10^{19}$ m^{-3} were examined, see Fig. 2b. These experiments confirmed importance of the initial RE seed for the subsequent evolution of REs. Furthermore, acceleration (and possibly avalanching) of the RE population in the discharge plateau is testified by loss of highly energetic REs (as observed by the Pb shielded detector) in the current ramp-down phase with zero U_{loop}. Interestingly, the data also demonstrated that a low-amplitude secondary fuel puff in the early current ramp-up phase can hinder production of the high energy REs only.

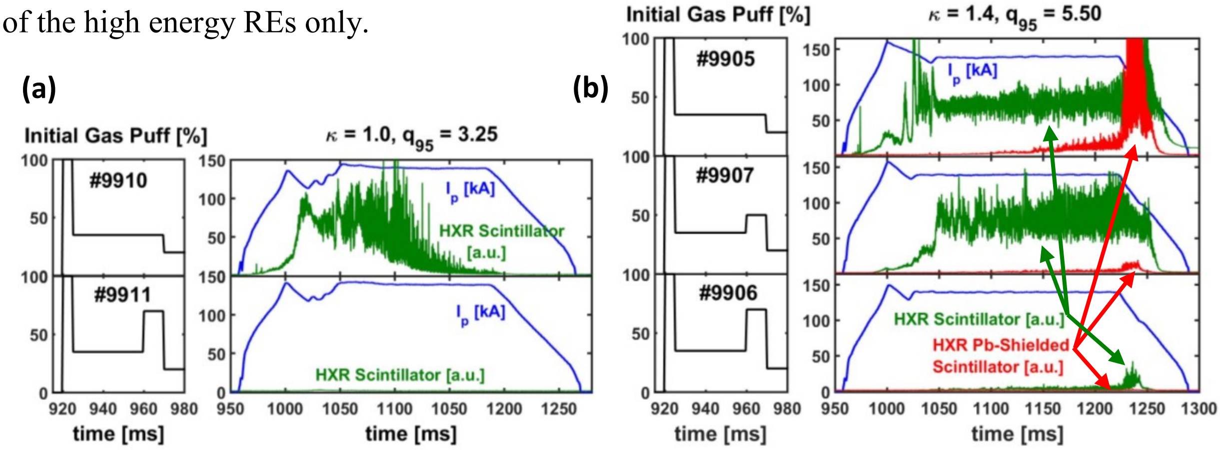

Figure 2. Fuelling scenarios at the plasma breakdown and its impact on RE population in the COMPASS tokamak: (a) circular plasma ($\kappa = 1$, $q_{95} = 3.25$) and (b) elongated plasma ($\kappa = 1.4$, $q_{95} = 5.50$) cross-sections.

3. Confinement of Runaway Electrons in shaped plasmas

In order to assess influence of plasma shaping on the RE confinement, HXR data from discharges with circular plasma and elongated plasma cross-sections were compared, see Fig. 3. Notice that in these studies, plasma current was kept constant in order to maintain similar plasma temperatures ($T_e \sim 550$ eV), and two levels of plasma density were examined. The HXR data give evidence of improved confinement in shaped plasmas. Indeed, in the low density case ($n_e \sim 1.9 \cdot 10^{19}$ m^{-3}, blue line) data from the shielded detector indicate continuous loss of the energetic REs in the case of circular plasmas, while in elongated plasmas the energetic REs are lost in a massive amount only at current ramp-down. At higher density ($n_e \sim 3.1 \cdot 10^{19}$ m^{-3}, red line) the evidence is even stronger, with early loss of all REs in the circular plasma, while some energetic REs survive in the elongated plasma.

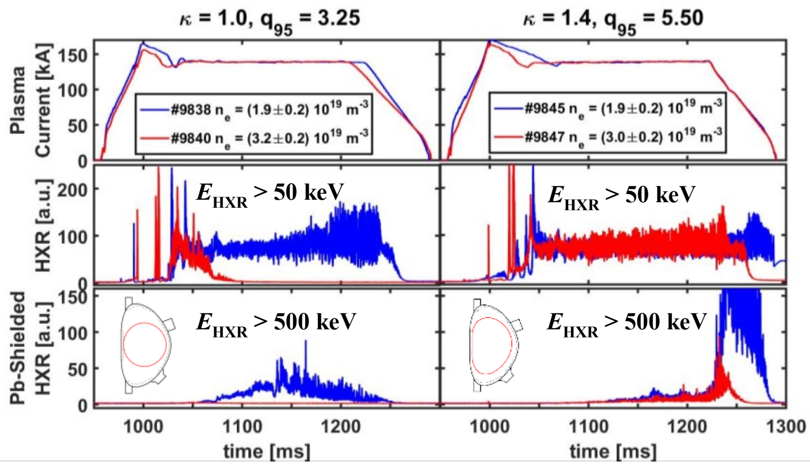

Figure 3. Plasma shaping and RE confinement in the COMPASS tokamak

However, interpretation of these observations is challenging and beyond available models. Among others, a possible interplay between the safety factor (magnetic field helicity) profile and the RE confinement have been discussed. Notice that at a constant plasma current the edge safety factor q_{95} increases with plasma elongation, which may strongly influence MHD properties of the discharge. To this end, RE confinement in elongated COMPASS discharges was studied as a function of increasing plasma current at a constant plasma density ($n_e \sim 2.5 \cdot 10^{19}$ m^{-3}). The results confirmed that the RE losses tend to increase with decreasing edge safety factor q_{95}, see Fig. 4. However, the HXR radiation data also reflected rather sudden loss of the RE population; at the time of the loss, a clear onset of MHD activity was observed in several discharges.

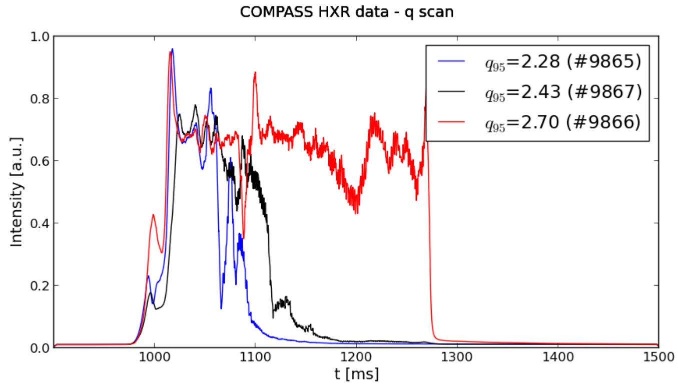

Figure 4. RE confinement in the COMPASS elongated plasmas with variable edge safety factor q_{95}

4. Conclusions

Dedicated experiments at COMPASS tokamak proved that initial fuelling of the discharge predetermines the RE population. Improved confinement of REs was observed in shaped plasmas; data indicate a significant role of the MHD effects. Future COMPASS RE campaigns shall be focused, among others, on benchmarking studies of the models, in particular on LUKE [11], and on field independent plasma heating via Neutral Beam Injector.

Acknowledgments

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The COMPASS operation has been supported by the MSMT project LM2011021. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] V. Plyusnin et al., Proc. 25th Fusion Energy Conference, St Petersburg 2015, EFDA-JET-CP(14)06/34
[2] A. Loarte et al., Nuclear Fusion 51 (2011) 073004
[3] B. Esposito et al, Phys Plasmas 10 (2003) 2350
[4] E. M. Hollmann et al, Nucl. Fusion 53 (2013) 083004
[5] F. Saint-Laurent, Proc. 36th EPS Conf. on Plasma Physics, Sofia 2009, ECA Vol. 33E, P4.205
[6] E.D. Frederickson, Nucl. Fusion 55 (2015) 013006
[7] R. Yoshino, S. Tokuda and Y. Kawano, Nuclear Fusion 39 (1999) 151
[8] R. Panek at al., invited talk at this conference, to be submitted to Plasma Phys. Control. Fusion
[9] M. Vlainic et al, poster presentation at this conference, P4.108
[10] M. Vlainic et al, accepted by J. Plasma Phys
[11] J. Decker, Y. Peysson, EUR-CEA-FC-1739 (2004)