EUROFUSION WPJET1-CP(16) 15187

P Martin et al.

Physics, control and mitigation of disruptions and runaway electrons in the EUROfusion Medium Size Tokamaks science programme

Preprint of Paper to be submitted for publication in Proceedings of 26th IAEA Fusion Energy Conference

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 views and opinions expressed herein do not necessarily reflect those of the European Commission.

Physics, control and mitigation of disruptions and runaway electrons in the EUROfusion Medium Size Tokamaks science programme

Martin P.[1], Blanken T.[2], Buratti P.[3], Carnevale D.[3], Causa F.[3], Decker J.[4], Duval B.[4], Esposito B.[3], Fable E.[5], Felici F.[2], Ficker O.[8], Fil A.[6], Gobbin M.[1], Gospodarczyk M.[3], Granucci G.[7], Hoelzl M.[5], Kudlacek O.[1], Maraschek M.[5], Marrelli L.[1], Mlynar J.[8], Nardon E.[9], Nocente M.[7], Paccagnella R.[1], Papp G.[5], Pautasso G.[5], Piovesan P.[1], Piron C.[1], Plyusnin V.[10], Popovic Z.[11], Sheikh U.[4], Sommariva C.[9], Sozzi C.[12], Valisa M.[1], Vlainic M.[13], Zanca P.[1] and the EUROfusion MST1*, the ASDEX Upgrade, MAST and TCV teams

[1]University of Padova and Consorzio RFX, Padova, Italy, [2]Eindhoven University of Technology, The Netherlands, [3]ENEA Unità Tecnica Fusione, Frascati, Italy, [4]Ecole Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), Lausanne, Switzerland, [5]Max-Planck-Institut für Plasmaphysik, Garching, Germany, [6]Princeton Plasma Physics Laboratory, Princeton, NJ, USA, [7]Dipartimento di Fisica, Università di Milano-Bicocca, Milano, Italy [8]Institute of Plasma Physics of the CAS, Praha 8, Czech Republic, [9]Commissariat à l'énergie atomique, IRFM, Saint-Paul-lès-Durance, France, [10]Centro de Fusão Nuclear, IST, Lisbon, Portugal, [11]Universidad Carlos III de Madrid, Leganes, Madrid, Spain, [12]Istituto di Fisica del Plasma, CNR, Milano, Italy, [13]Department of Applied Physics, Ghent University, 9000 Ghent, Belgium.

E-mail contact of main author: martin@igi.cnr.it

Abstract. EUROfusion dedicates a significant effort to disruption and runaway electron (RE) research in its Medium Size Tokamaks (MST) Task Force, which coordinates the European activities in ASDEX-Upgrade, MAST-U and TCV. The MST disruption and RE programme addresses prediction, avoidance and mitigation and is supported by simulation activities and by the contribution of other European tokamaks. This paper summarizes the main results obtained in this field within the MST Task Force since the last IAEA Fusion Energy Conference.

1. Introduction

Disruptions are a rapid loss of the confined plasma and its current, often producing a beam of runaway electrons (RE) [1]. Disruptions are probably the most severe among the off-normal events that may happen in a tokamak, since they can cause dramatic damage to the device. The average energy density on the wall during disruptions scales as L^3 - where L is the linear size of the plasma. This means that from JET to ITER the disruption loads increase by an order of magnitude. Maximum electromagnetic forces on the vacuum vessel are of the order of 4 MN in JET and are expected to be of the order of several tens of MN in ITER, where heat load may also cause severe first wall melting.

Disruptions represent a complex, multi-faceted issue. Its solution calls for a network of tools, often with redundancy and following a sequence of prediction, avoidance and mitigation, with the latter capable to successfully intervene also in completely unpredictable cases. To this end EUROfusion, the European Consortium for the Development of Fusion Energy [2], dedicates a significant effort to disruption research. This happens amongst others in its Medium Size Tokamaks (MST) Task Force [3], that coordinates the European activities in the ASDEX-Upgrade (AUG) [4], MAST-U [5] and TCV [6] tokamaks.

* See appendix of H. Meyer et.al. (OV/P-12) Proc. 26th IAEA Fusion Energy Conf. 2016, Kyoto, Japan

The MST disruption and RE programme developed along the above three keywords - prediction, avoidance and mitigation - with experiments performed during the 2014 and 2015/16 campaigns in AUG and TCV and an intense modelling activity, targeting in particular: (a) the mitigation via Massive Gas Injection (MGI), (b) the development of scenarios for reliable production and mitigation of RE during disruptions, (c) the development of tools for disruption prediction and avoidance. All this is done by exploiting the added value of devices with different size, aspect ratio and shapes and with the support of other European devices. This paper – based on topical papers at this conference – provides an overview of this broad scientific effort and is organized as follows. Section 2 is dedicated to disruption mitigation, while section 3 covers disruption prediction and avoidance. Section 4 deals with runaway electrons and in section 5 conclusions are drawn.

2. Disruption mitigation

A well-established technique for disruption mitigation is based on the injection of noble gas – either in the gaseous or frozen state – in the pre-disruptive plasma. The injected atoms are assimilated by the plasma and radiate part of the thermal energy, decreasing therefore the amount of energy conducted to the divertor and first wall during the thermal quench (TQ). The injection of impurity atoms may also influence the current quench (CQ) – and therefore the forces caused by the disruption – and the runaway electron dynamics. Injection of impurity in the gaseous state is known as MGI. Experiments on disruption mitigation with MGI systems have been performed in AUG [7,8] and TCV [6].

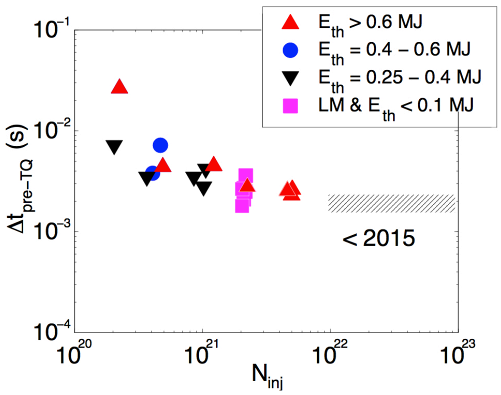

Fig.1 (taken from ref. [8]): $\Delta t_{\text{pre-TQ}}$ vs. inumber of injected neon atoms N_{inj} for various ranges of plasma thermal energy E_{th}. The hatched area represents older results published in [7].

In AUG, MGI is based on two in-vessel fast valves, located approximately 180 degrees toroidally apart, complemented by two out-of-vessel electromagnetic valves (a third one is installed but was not available during the 2015/16 campaign). AUG experiments have focused on exploring the influence of the amount of injected gas, and in particular on the search for the minimum quantity of gas for mitigation that is still compatible with ITER requirements in terms of radiation fraction and forces. This follows the present design of the ITER disruption mitigation system, where the idea of simultaneous disruption mitigation and RE suppression has been discarded in favour of a two stages system [9]. In the first stage a set of injector will be used to mitigate heat loads and control the ITER current decay time within the prescribed 50-150 ms interval [9], while a second set of injectors will be later used to suppress RE. An exhaustive summary of the recent results can be found in [7,8].

The minimum amounts of gas used in the AUG MGI system has been decreased to $N_{\text{inj}} \approx 10^{20}$-$10^{22}$ atoms, i.e. about two orders of magnitude smaller with respect to the maximum values used before. MGI has been operated in healthy plasmas with I_p=1 MA, magnetic energy E_{mag}=1.4 MJ and edge safety factor $q_{95} \approx$ 4.3. Unfortunately more relevant scenarios close to the beta limit, with high thermal energy, are not reproducibly available in AUG as in those conditions tearing modes deteriorate the plasma before the disruption happens.

A figure of merit for gas assimilation is the pre-thermal quench time $\Delta t_{\text{pre-TQ}}$, defined as the time lag between the appearance of the injected impurity atoms at the plasma edge and the start of the thermal quench. The gas which is assimilated during this phase will radiate and influence the initial current decay rate. The duration of this phase, i.e. the value of $\Delta t_{pre\text{-}TQ}$, is therefore very important. AUG shows that $\Delta t_{pre\text{-}TQ}$ changes only by a factor of two going from $N_{inj} \approx 10^{23}$ to $N_{inj} \approx 10^{21}$, but drastically increases below 10^{21}, as shown in Fig. 1. For $4\times10^{20} < N_{inj} < 10^{23}$ the CQ duration in AUG remains in the prescribed ITER range, while below 4×10^{20} it hits the upper limit for ITER. When N_{inj} decreases below 10^{21}, electromagnetic forces increase. The pre-thermal quench phase has been modelled with Astra-Strahl [10], obtaining agreement with neon injection experiments, which opens the possibility of using these codes for predicting ITER mitigation. Experimental data also hint that decreasing the injected gas amount leads to an increase of the thermal loads directly deposited on the divertor plates, but the inherent 3-D nature of the energy flow and the limited diagnostic coverage does not allow to draw firm conclusions, yet.

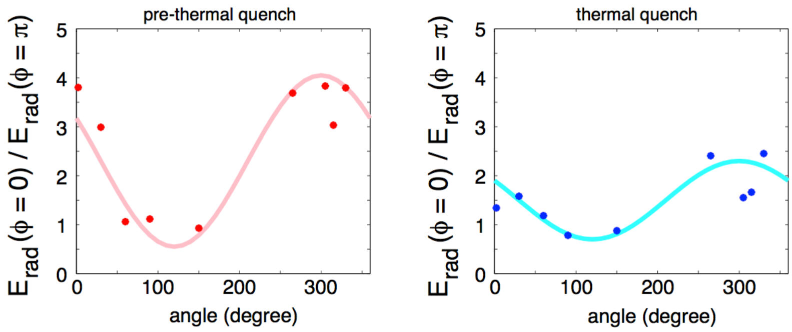

Fig. 2 (taken from ref. [8]): Ratio between the energies radiated in two toroidally opposite sectors $E_{rad}(\varphi= 0)/E_{rad}(\varphi=\pi)$, where $\varphi=0$ is the toroidal angle in front of the injection valve, during the pre-thermal quench (left) and thermal quench (right) vs. position of the maximum n=1 component of the radial magnetic field.

The combined exploitation of the AUG MGI and active magnetic coil systems has allowed the study of the toroidal asymmetry of the radiation distribution in plasmas disrupting because of locked modes. This is particularly important since rotating MHD modes in rotating plasmas help in reducing the toroidal asymmetry of the injection due to the discrete valve location, but this effect is lost if the mode is locked. The NIMROD Code predicts that the location of the island X-point with respect to the valve influences significantly the magnitude of the asymmetry [11]. The AUG active coil system allows for the reproducible relative positioning of the locked mode with respect to the MGI valves. The experiment, performed in ohmic plasmas driven to density limit – where a mode with a dominant n=1 character is induced – shows that the ratio of the energies radiated in two toroidally opposite sectors $E_{rad}(\varphi= 0)/E_{rad}(\varphi=\pi)$, where φ is the toroidal angle, reaches 4 and 2.5 during the pre-TQ and the TQ respectively, as shown in Fig. 2 where this ratio is plotted vs. the position of the maximum n=1 perturbed radial field $B_{r,n=1}$. The JOREK code, which was successfully used to model deuterium MGI in JET, is presently being applied to AUG and extended to impurity MGI, as well as being complemented by a test particle module for RE studies [12,13].

Experiments on MGI have started also in TCV [6], using one Parker miniature high speed, high vacuum pulse valve coupled to a converging diverging nozzle and a high pressure reservoir of 150cc. The valve is positioned approximately 400mm from the main plasma chamber allowing the injected gas to reach the plasma in as little as 1ms after valve opening. Initial results on injection at different density, using both Argon and Neon, are encouraging. The variety of plasma shapes and position allowed by TCV will provide an effective test-bench for this system in the forthcoming campaigns.

3. Disruption avoidance and prediction

Disruption avoidance techniques provide a tool to limit the number of cases the mitigation system has to deal with, or facilitate its work by allowing for soft-landing of ill plasmas. The possibility of avoiding disruptions in high-risk plasma scenarios has been subject of experiments performed in both AUG and TCV. Disruption avoidance through MHD stabilization via localized injection of Electron Cyclotron waves on the mode q=2 resonant surface has been studied, complemented also by the use of static or dynamic applied magnetic perturbations used to control the locked mode position or to entrain the mode – the latter aiming at an optimal deposition of EC waves.

Following positive results obtained in AUG L-mode density limit plasmas - where disruption avoidance via ECCD at q was achieved, with the discharge rescued and maintained for about half a second after switching off EC injection [14] – the same technique has been applied to H-mode density limit plasmas. While in L-mode EC injection is performed following an instability trigger based on locked mode detection and on loop voltage measurement, in H-mode an effective EC trigger is still under study, so the experiments have been performed firing EC in feed-forward mode. Disruption avoidance has been achieved at the density limit in H-mode up to 3.5 s. [15].

Experiments aiming at entraining locked mode to a slowly rotating magnetic perturbation (5 Hz) have been performed in AUG. The locked mode has successfully been anchored to the external perturbation to avoid or delay disruption [16]. No disruptions have been observed with this technique as far as the NBI power was below 10-12 MW, but experiments are at the moment not completely reproducible, so no firm conclusions can be drawn at the moment. Indications of unexpected or 'unhealthy' behaviour of the plasma – that could be symptom of an incoming disruption – are detected based on modelled plasma evolution and used as an input signal to a pulse supervision system. This is being done with the RAPTOR code in AUG and TCV [17,18]. The code gives detailed real-time information about profiles that can be compared to known limits and to the expected plasma evolution. This also provides an avoidance tool, since it allows to avoiding regions of parameter space where the plasma is at risk of disruption.

The EUROfusion disruption prediction activities – developed jointly by JET [19] and MST – are focused on real-time prediction tools based on physics signals and models, with reduced or even eliminated need for training on large databases, which would allow an easy generalization. More information on this topic can be found in [19].

4. Runaway electrons

Disruptions – and sometimes the use of disruption mitigation tools like MGI – may produce through an avalanche process a beam of high-energy relativistic runaway electrons that carry a significant fraction of the plasma current. This means that in large tokamaks RE beam current may be as high as several mega-amperes, potentially causing very serious damage if its confinement is lost in an uncontrolled way. The study of the RE physics and of the processes for their control and/or suppression is therefore of extremely high importance for ITER [9,20]. European devices have contributed to the ITPA activity to study the onset, growth, and decay of relativistic electrons, which has shown that loss mechanisms other than collisional damping may play a dominant role in the dynamics of the RE population [21]. More recently, a strong effort on RE mitigation has started in MSTs [22,23] and in other European devices (JET [19], COMPASS [24], FTU [25] and RFX-mod [26]). The recent campaigns in AUG and TCV have allowed the development, for the first time, of scenarios for the reproducible generation of RE during disruptions. This is a necessary step to study in a reliable and reproducible way the RE control and suppression with a variety of tools. In AUG [8,22] RE are produced by injecting Argon in a I_p=0.8 MA, B_T=2.5 T, low density (n_e≈2.5-

3.6×10^{19} m^{-3}), L-mode, inner-wall limited circular plasma. Plasma is heated with 2-2.5 MW of ECRH, which is applied for 100-200 ms just before the Argon injection (0.05-0.2 bar•l).

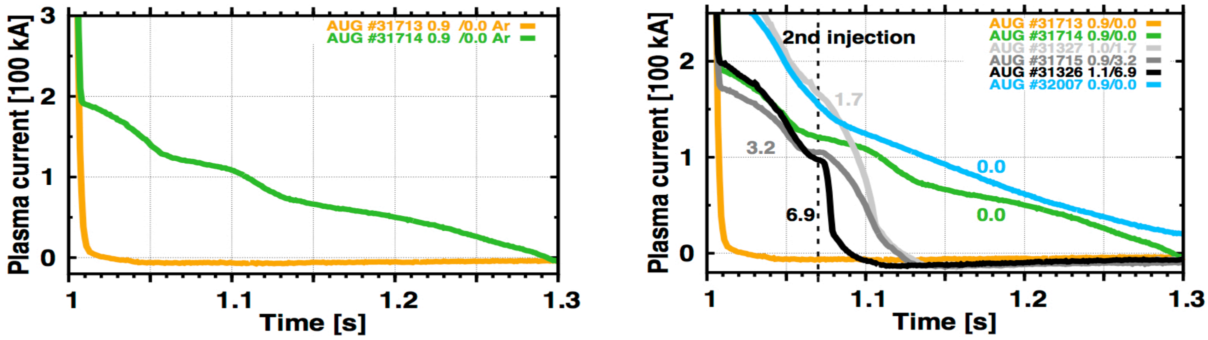

Fig. 3. (a-left) waveform of the plasma current for two discharges, #31713 w/o RE and #31714 with RE (following Ar injection). (b-right) waveform of the plasma current for #31713 w/o RE and for several discharges with RE where a second Ar injection is used. Numbers close to waveforms correspond to Ar pressure in the valve

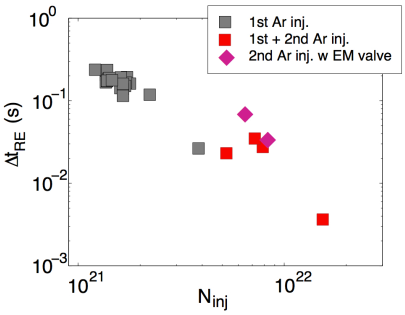

Fig. 4 (taken from ref. [8]): lifetime of RE beam (Δt_{RE}) vs. total amount of injected argon particles (N_{inj})

A RE beam, carrying current up to 420 kA for 480 ms is formed. Time traces of the plasma current for a discharge without Ar injection and for one with are shown in Fig. 3-a. The latter clearly shows the onset of the RE beam. The circular plasma carrying the RE beam is vertically stable, and its current is controlled. The measured total radiated energy is of the order of magnitude of the initial kinetic and magnetic energy of the RE beam, which hints a significant role of the radiation in the RE energy dissipation. A second Ar injection, 70 ms after the first Ar puff, is used to suppress the RE, as shown in Fig. 3.b for several discharges where different Ar pressures were used. The RE current decay rate grows with the amount of injected argon (Fig. 4). This suggests that RE energy loss by collision with the electrons and the high Z impurity atoms – induced by friction and radiation - is a significant RE dissipation mechanism.

Reproducible generation of RE via MGI in very low-density ($n_e \leq 2\times10^{18}$ m^{-3}) 200 kA, B_T=1.43 T, ohmic, L-plasmas is obtained also in TCV. An example is shown in Fig. 5, which reports the plasma current and the loop voltage. Full conversion of the pre-injection plasma current into RE beam current is achieved. Thanks to the flexibility of TCV future experiments will aim at determining the effects of plasma shaping on RE generation and dissipation. Thanks to AUG and TCV experiments and to others in COMPASS [27] new data have been added to the database of disruption generated RE [28].

RE suppression is attempted also with tools based on control of electromagnetic quantities. Following positive results obtained in RFX-mod used as a tokamak [26] – where the application of an external magnetic perturbation produced by the 192 active coils of that device lead to the production of stochastic magnetic field and eventually to substantial de-correlation of RE, a process confirmed by simulations with the ORBIT code – a similar experiment has been repeated in AUG. The mismatch between the relatively high edge safety factor of the plasma which carries the RE beam and the spatial periodicity of the perturbation applied with the external coils, together with the large distance between the inner-wall limited plasma and the coils placed on the low-field side and with the low amplitude of the perturbation, were predicted not to allow a significant stochasticization as in RFX-mod. Nonetheless, the experiments have given very interesting and positive results [29], briefly

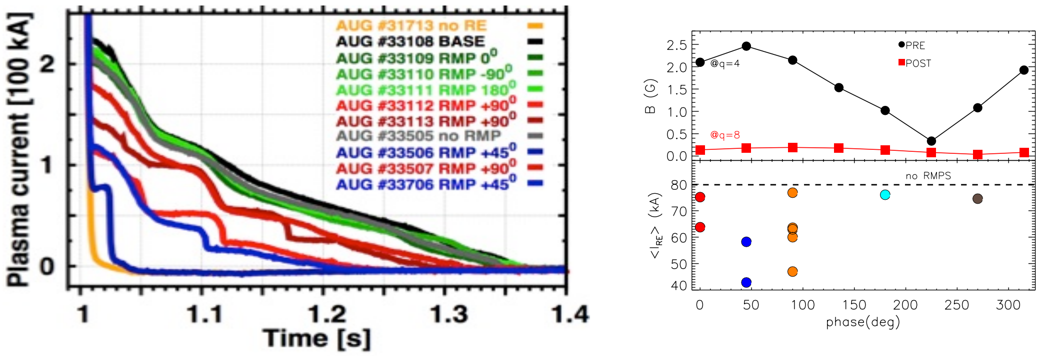

Fig. 5: (a-left) waveforms of AUG post-disruption plasma current for various discharges where magnetic perturbations with different phases have been applied. (b-right): time-averaged amplitude of the RE beam normalized to its value I_{RE0} immediately after the disruption is triggered, I_{RE}/I_{RE0} vs. relative phase between the two rows of B-coils Δφ.

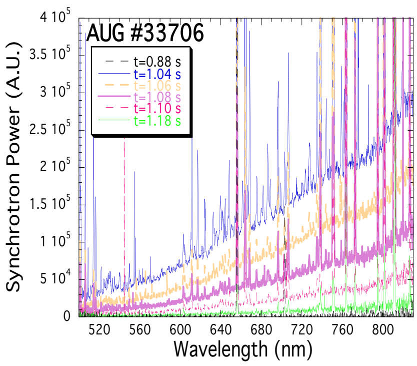

Fig. 6: Synchrotron spectra in AUG during post-disruption runaway plasmas.

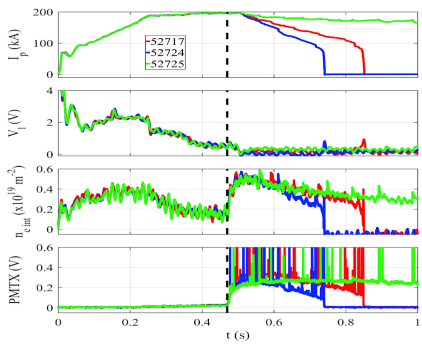

Fig. 7: Waveforms of plasma current I_p, toroidal loop voltage V_l, electron density ne and Hard X-ray emission (PMTX) for TCV discharges with three different pre-programmed central solenoid currents.

described in the following. A magnetic perturbation is applied in AUG 0.5 s before the disruption is triggered with the Ar injection. The magnetic perturbation is produced by the two set of the so-called B-coils. Each set is composed by a row of 8 coils, arranged all around the torus on the LFS. The two sets are symmetric with respect to the equatorial plane. The perturbation has a dominant n=1 structure, and its poloidal spectrum can be changed by varying the relative phase Δφ of the currents between the up and bottom coil rows. The result is summarized in Fig. 5. Fig. 5-a shows the time evolution of the RE beam currents for several otherwise similar discharges, were different Δφ have been used. The influence on the RE beam is evident for some of the discharges, with a variation that goes from strong suppression to no effect. This finds a clearer representation in Fig. 5-b. This figure shows, as a function of Δφ, in the top frame the normalized amplitude of the n=1 magnetic perturbation component δB, which is resonant with q_{edge}=4, and in the bottom frame the time-averaged amplitude of the RE beam normalized to its value I_{RE0} immediately after the disruption is triggered, I_{RE}/I_{RE0}. It is evident that I_{RE}/I_{RE0} depends on Δφ and it is minimum when δB is maximum. The detailed physics process involved in this strong RE mitigation evidence is still not clear and it is likely to be connected with an influence on the MHD plasma stability at the time of the disruption, but the results are very encouraging and open new perspectives for RE control via an applied magnetic perturbation. Information on the dynamics of the RE beam can be provided by synchrotron radiation measurements performed with a Runaway Electron Imaging and Spectrometry system (recently ported from the FTU tokamak to AUG [25]) whose data analysis is in progress. A preliminary example of the spectra acquired by the REIS in AUG during the runaway beam phase is shown in Fig. 6.

MGI to produce RE combined with pre-programmed waveforms of the ohmic heating central solenoid current has been tested also in TCV. This approach has been successful as shown in Fig. 7, where three different cases are shown: (a) the reference case (red curve) where no active action is undertaken; (b) the case where the RE beam is mitigated forcing it to decrease more rapidly ($dI_{OH}/dt<0$); and (c) a counter-example made to test the concept, where by imposing $dI_{OH}/dt>0$ the RE beam is reinforced. Real-time control to obtain the ramp-down of disruption-generated RE beams has been implemented in TCV, following successful experiments in FTU [23,25,30]. Fig. 8 shows the waveforms of the plasma current and hard X-rays (PMTX) for RE feedback suppression cases in TCV (after t~0.5 s) and FTU (after t~0.4 s). The RE activities in the MST devices are complemented by an intense accompanying work in other European tokamaks. In addition to the already mentioned control experiments in RFX-mod, strong contributions came from COMPASS and FTU, which are both well equipped for these studies. Among several contributions of these two devices – which are extensively reported in papers [24,25,27] – we mention the studies on the influence of spontaneous MHD on the RE mitigation and losses (Fig. 9, for example, reports for COMPASS the coherence diagram between the Hard X-Ray – a proxy for RE losses - and the Mirnov coil signals, indicating that when magnetic islands are present RE losses are well correlated) .

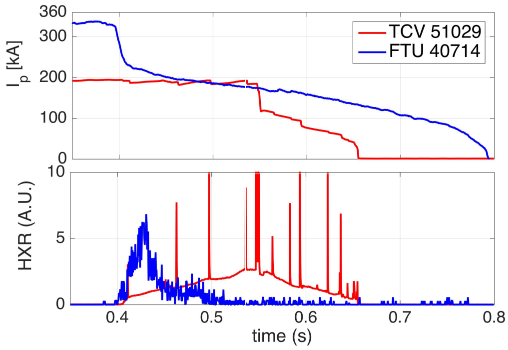

Fig. 8: RE current ramp-down obtained with the feedback control system in TCV and FTU. Top: plasma current, bottom: Hard X-Ray signal

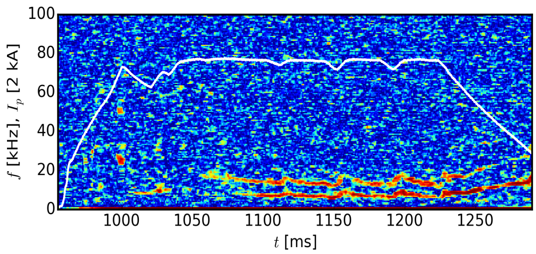

Fig. 9: (a-left) Coherence diagram of Hard X-Ray and magnetic data in COMPASS discharge

5. Conclusions

Disruption and runaway electron studies have been assigned very high priority in the programme of the MST task force since its very beginning. This choice, supported by an increasing involvement of the EU community in these experiments, has been rewarded by numerous experimental results and by a growing effort on modelling. The work on disruption mitigation has focussed to stewarding the design of the ITER disruption mitigation system, in particular addressing key issues as the effectiveness of the MGI tool as a function of the amount of injected gas. Further studies are needed, in particular to precisely quantify the 3D heat loads patterns and to extend MGI experiments in high thermal energy plasmas. On the avoidance side, efforts exploiting electron cyclotron, applied magnetic perturbation and a plasma supervision system like RAPTOR have given very promising results. Bringing these tools to full maturity, and in particular exploiting them in the broadest set of plasma scenarios, will be the challenge for the coming years. Finally, since the last 2014 IAEA FEC big leaps have been made in the field of runaway electron control. Reliable runaway electron scenarios are now routinely produced in many European tokamaks, which serve as test bed for several suppression tools using MGI and magnetic control.

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 views and opinions expressed herein do not necessarily reflect those of the European Commission.

---

[1] HENDER, T., in "Active Control of Magneto-hydrodynamic Instabilities in Hot Plasmas", V. Igochine (2015), Springer.

[2] see https://www.euro-fusion.org

[3] MEYER, H., "Overview of progress in European Medium Sized Tokamaks towards an integrated plasma-edge/wall solution", in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)

[4] KALLENBACH, A., "Overview of ASDEX Upgrade results", in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)

[5] KIRK, A., "verview of recent physics results from MAST", in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)

[6] CODA S., et al., "Overview of the TCV Tokamak Program: Scientific Progress and Facility Upgrades", in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)

[7] PAUTASSO, G. et al., Nuclear Fusion **55** (2015) 033015

[8] PAUTASSO, G. et al., "Disruption mitigation studies at ASDEX Upgrade in support of ITER", paper I4.114, 43th EPS Plasma Physics Conference, Leuven, (2016), also submitted to PPCF (2016).

[9] LEHNEN, M., J. Nucl. Mat. **463** (2015) 39

[10] FABLE, E., Nucl. Fusion **56** (2016) 026012

[11] IZZO, V. et al, Phys. Plasmas **20** (2013) 056107

[12] NARDON, E. "Modelling of gas penetration, MHD activity, radiation and runaway electrons in disruptions mitigated by massive gas injection", paper I4.115, 43th EPS Plasma Physics Conference, Leuven, (2016), also submitted to PPCF (2016).

[13] SOMMARIVA, C. et al, paper P2.006, 43th EPS Plasma Physics Conference, Leuven, (2016)

[14] GRANUCCI, G., "Stable Operation at Disruptive Limits by Means of EC at ASDEX Upgrade", paper P1.108, 42th EPS Plasma Physics Conference, Lisbon, (2015)

[15] ESPOSITO B, MARASCHEK M., priv. communication (2016)

[16] PACCAGNELLA, R. et al., paper P1.027, 43th EPS Plasma Physics Conference, Leuven, (2016)

[17] FELICI F, "Control-oriented modeling of tokamak plasmas for real-time plasma monitoring, profile control and MHD control", paper I4.112, 43th EPS Plasma Physics Conference, Leuven, (2016), also submitted to PPCF (2016).

[18] FELICI, F. et al., "Real-time model-based plasma state estimation, monitoring and integrated control in TCV, ASDEX-Upgrade and ITER, in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)

[19] JOFFRIN, E., "Disruption study advances in the JET metallic wall", in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)

[20] HOLLMANN, E.M. et al., Phys. Plasmas **22** (2015) 021802

[21] GRANETZ, R.S. et al., Phys. Plasmas **21** (2014) 072506

[22] PAPP, G. et al., "Runaway electron generation and mitigation on the European medium sized tokamak ASDEX Upgrade and TCV", in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)

[23] ESPOSITO, B., "First experimental results of runaway beam control in TCV", in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)

[24] VLAINIC M., et al., "Synchrotron Radiation from Runaway Electrons in COMPASS Tokamak", paper P4.108 in Proc. EPS42th EPS Plasma Physics Conference, Lisbon, (2015)

[25] ESPOSITO, B. et al., "Runaway generation and control", paper I4.116, 43th EPS Plasma Physics Conference, Leuven, (2016), accepted for publication in PPCF (2016).

[26] GOBBIN, M. "Runaway electron mitigation by resonant and non-resonant magnetic perturbations in RFX-mod tokamak discharges, paper O4.136 in Proc. EPS42th EPS Plasma Physics Conference, Lisbon, (2015)

[27] MLYNAR, J., "Losses of runaway electrons in MHD-active plasmas of the COMPASS tokamak", in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)

[28] PLYUSNIN , V., "Comparison of Runaway Electron Generation Parameters in Small, Medium-sized and Large Tokamaks – A Survey of Experiments in COMPASS, TCV, ASDEX-Upgrade and JET", in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)

[29] GOBBIN, M. et al., "Runaway electrons mitigation by 3D fields: new insights from ASDEX Upgrade and RFX-mod experiments", in proc. 58th Annual Meeting of the American Physical Society, Division Of Plasma Physics (2016)

[30] CARNEVALE, D., "Analysis of runaway beam suppression experiments in FTU", in Proc. 26th IAEA Fusion Energy Conference, Kyoto, Japan (2016)