Contribution ID: **1480** Type: **Regular Poster**

[REGULAR POSTER TWIN] Shattered Pellet Injection experiments at JET in support of the ITER Disruption Mitigation System design

Wednesday 12 May 2021 12:10 (20 minutes)

A series of experiments have been executed at JET to assess the efficacy of the newly installed Shattered Pellet Injection (SPI) system in mitigating the effects of disruptions. In this contribution, the results from these JET SPI experiments are presented and their implications for the ITER disruption mitigation scheme discussed.
An effective Disruption Mitigation System (DMS) that minimizes thermal excursions, mechanical forces and effects of Runaway Electrons (RE) is mandatory for successful operation of ITER. The chosen ITER-DMS concept [1] is based on disruption mitigation through injection of shattered pellets, so-called SPI, which promises a deeper and faster penetration of radiating material compared to the commonly used Massive Gas Injection (MGI) valves as demonstrated on DIII-D [2].
Gaps in the understanding of the effectiveness of disruption mitigation with SPI still remain. To assist in addressing them, a new SPI system has been brought into operation during the most recent JET campaign and the efficiency in mitigating thermal and electromagnetic loads and in dissipating the energy of an existing RE-beam has been studied. The JET SPI experiments are a key element to allow extrapolation to ITER in terms of size, plasma current and plasma energy. Moreover, the ITER-like wall is essential to address injections with low impurity content without being impacted by high carbon levels. These experiments serve as basis for the benchmarking of models that are required to predict the performance of the ITER-DMS. The JET SPI is a three-barrel injector system capable of delivering neon, deuterium, argon and mixed pellets. By using mechanical punches, which are required to dislodge argon pellets, the velocity of the fired pellet and the resulting shard size and speed can be varied significantly [3].
In ITER, thermal load mitigation must ensure a high radiation fraction during the thermal (TQ) and current (CQ) quenches, while keeping the radiated power asymmetries to acceptable levels. To determine the optimum amount of neon needed to maximise the radiation, the fraction of neon injected together with deuterium into typical JET low and high energy H-mode plasmas was scanned for magnetic and thermal energies ranging respectively from 3.0 to 16 MJ and from 1.0 to 7.0 MJ. High radiated energies are reached for neon atom quantities >3-4x1021. However, due to potential variations in pellet velocities and shard size distributions, the achieved radiation level varies. Analysis of fast camera observations of the pellet shard ablation indicates differences in the material delivery that can be expected to affect the radiation efficiency. The achievable radiation levels depend on the fraction of thermal energy in the pre-disruptive plasma, though it should be noted that radiation asymmetries have an important impact on the assessment of the thermal load mitigation efficiency [4]. In addition, such asymmetries can lead to a local radiation flash sufficient to melt some areas of ITER beryllium first wall (FW). In order to determine the toroidal peaking factor of the radiation, either a good toroidal coverage with the bolometry diagnostic is required, or the toroidal distribution must be inferred from the change of the radiated power at a given toroidal location as a function of the location of the locked mode phase. At JET, the total radiated power can be estimated at two different toroidal locations [5]. By superimposing a non-axisymmetric n=1 perturbation field [6], the radiation asymmetry was measured as a function of the locked mode phase. The experiments indicate that asymmetries decrease with increasing plasma energy. A dedicated modelling programme accompanies these experiments to assist the data interpretation and to provide the extrapolation to ITER [7].
Low radiation levels during the unmitigated CQ are expected to lead readily to melting of the ITER FW due to high plasma thermal fluxes. This has in fact already been observed in JET after unmitigated disruptions with plasma currents > 2.0 MA. It must therefore be ensured that the magnetic energy will be fully radiated and hence that a late material injection, i.e. after the TQ, is still effective. In order to test the mitigation scheme, where the DMS is triggered after a TQ, a density limit disruption has been provoked on JET by deuterium MGI into an ohmic plasma, with the SPI triggered such that the shards arrive ~9 ms after the start of the CQ (see Figure 1). As a result, the CQ has been accelerated and the radiated energy has been more than doubled compared to the unmitigated reference.

Indico rendering error

Could not include image: [404] Error fetching image

To keep the electromagnetic forces on the ITER blanket modules within the design limits, the CQ times must remain within a range 50-150 ms [8]. The JET experiments have clearly demonstrated the controllability of the

CQ rate by injecting different quantities of neon. Moreover, the effects of asymmetric Vertical Displacement Events are found to be fully mitigated with SPI, when the vertical displacement is detected with sufficient warning [9].

For ITER, initial modelling predicts that 6x1024 hydrogen atoms must be assimilated by the plasma to avoid the generation of REs [10]. This scheme was successfully tested at JET by injecting deuterium with the SPI into RE-prone disruptions initiated by a pure argon MGI. In ITER, injection of multiple pellets is required to achieve sufficiently high density for avoidance of REs. The material assimilation during dual injection in JET using the largest two barrels was assessed. It was found, similarly to DIII-D, that the simultaneous arrival of the shards from the two pellets is essential to maximise the assimilation. The available time to inject high-Z material for heat load mitigation after an attempt has been made to raise the density for RE avoidance was determined by injecting a large, pure deuterium SPI into a high thermal energy plasma. Cooling durations up to the TQ of several tens of ms were achieved. On the contrary, by doping the deuterium pellet with just 2% neon, the cooling duration is reduced to a few ms, which would impose severe constraints on the synchronisation of the ITER-DMS injectors. These results are in agreement with modelling for ITER using the INDEX code, where the dilution cooling by pure deuterium SPI is found to avoid an immediate radiative collapse and delays the TQ trigger [11].

In the case of accidental RE generation in ITER, a scheme to dissipate their energy must be in place. Injections of both pure argon and neon shards into a fully developed RE-beam in JET can reduce the RE current. However, in contrast to high-Z injections, it was observed that pure deuterium injection could avoid high energy deposition during the final loss phase of the RE-beam.

On ITER hydrogen is planned for use both as propellant and main pellet material for RE avoidance throughout all operational phases, raising the issue of a potential detrimental effect on the subsequent pulses due to dilution of the plasma main species with residual hydrogen. Tests in H-mode plasmas at JET are helping ITER to determine whether or not this will be an issue.

[1] M.Lehnen et al., Proceedings 27th IAEA-FEC (2018).
[2] N.Commaux et al., Nucl.Fus. 56, 2016, 046007.
[3] L.Baylor et al., subm. 28th IAEA-FEC (2020).
[4] U.Sheikh et al., subm. 28th IAEA-FEC (2020).
[5] J.Lovell et al., subm. Rev.Sci.Instr.
[6] S.Jachmich et al., 22nd PSI-conference (2016).
[7] E.Nardon et al., subm. 28th IAEA-FEC (2020).
[8] M.Sugihara et al., Proceedings 24th IAEA-FEC (2012).
[9] S.Gerasimov et al., subm. 47th EPS-conference Plasm.Phys. (2020).
[10] J.R.Martin-Solis et al., Nucl.Fus. 57, 2017, 066025.
[11] A.Matsuyama et al., subm. 28th IAEA-FEC (2020).

Country or International Organization

ITER Organization

Affiliation

ITER Organization, Route de Vinon, CS 90 046, 13067 Saint Paul Lez Durance, France

Author: JACHMICH, Stefan (ITER Organization)

Co-authors: Dr KRUEZI, Uron (ITER organization); LEHNEN, Michael (ITER Organization); BARUZZO, Matteo (ENEA, Fusion and Nuclear Safety Depatment, C. R. Frascati, via E. Fermi 45 00044, Frascati, Roma (Italy)); BAYLOR, Larry R. (Oak Ridge National Laboratory); CARNEVALE, Daniele (Departement of Industrial Engineering, Università di Roma "Tor Vergata"); CRAVEN, Douglas (Culham Centre for Fusion Energy); EIDIETIS, Nicholas (General Atomics); FICKER, Ondrej (Institute of Plasma Physics of the Czech Academy of Sciences); GEBHART, Trey (Oak Ridge National Laboratory); GERASIMOV, Sergei (CCFE); HERFINDAL, Jeffrey (UsOakRidge); HOLLMANN, Eric M. (University of California San Diego); HUBER, Alexander (Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung –Plasmaphysik); Dr LOMAS, Peter (Culham Centre for Fusion Energy, Abingdon, OX143DB); Dr LOVELL, Jack (Oak Ridge National Laboratory); Dr MANZANARES, Ana (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid, Spain); MASLOV, Mikhail (Culham Science Centre); MYLNAR, Jan (Institute of Plasma Physics of the CAS, Prague, Czech Republic); PAUTASSO, Gabriella (IPP, Garching, Germany); PAZ-SOLDAN, Carlos (General Atomics); PEACOCK, Alan (JET Exploitation Unit); PLYUSNIN, Vladislav V (Instituto de Plasmas e Fusão Nuclear, Associação EURATOM-IST, Instituto Superior Tecnico); REINKE, Matthew (ORNL); REUX, Cedric (CEA, IRFM, F-13108 Saint Paul-lez-Durance, France.); Dr RIMINI, Fernanda (UKAEA); SHEIKH, Umar; SHIRAKI, Daisuke (Oak Ridge National Laboratory); Dr SILBURN, Scott (UKAEA); Dr SWEENEY, Ryan (MIT); WILSON, James (Culham Centre for Fusion Energy); HACQUIN, Sebastien (CEA, IRFM); KIM, Hyun-Tae (EUROfusion Consortium JET); JOFFRIN, Emanuell (EUROfusion Consortium JET)

Presenter: JACHMICH, Stefan (ITER Organization)

Session Classification: P3 Posters 3

Track Classification: Magnetic Fusion Experiments