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A new Disruption Mitigation System for deuterium–tritium operation at JET

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HIGHLIGHTS

- A Disruption Mitigation System based on massive gas injections has been designed.
- The DMS has been installed at the JET-tokamak for routine machine protection.
- The DMS is capable of a throughput of up to 4.6 kPa m^3.
- The new DMS is compatible with the deuterium–tritium operation at JET.

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ABSTRACT

Disruptions, the fast accidental losses of plasma current and stored energy in tokamaks, represent a significant risk to the mechanical structure as well as the plasma facing components of reactor-scale fusion facilities like ITER. At JET, the tokamak experiment closest to ITER in terms of operating parameters and size, massive gas injection has been established as a disruption mitigation method. As a “last resort” measure it reduces thermal and electromagnetic loads during disruptions which can potentially have a serious impact on the beryllium and tungsten plasma-facing materials of the main chamber and divertor. For the planned deuterium–tritium experiments, a new Disruption Mitigation System (DMS) has been designed and installed and is presented in this article. The new DMS at JET consists of an all metal gate valve compatible with gas injections, a fast high pressure eddy current driven valve, a high voltage power supply and a gas handling system providing six supply lines for pure and mixed noble and flammable gases (Ar, Ne, Kr, D_2, etc.). The valve throughput varies with the injection pressure and gas type (efficiency – injected/charged gas 50–97%); the maximum injected amount of gas is approximately 4.6 kPa m^3 (at maximum system pressure of 5.0 MPa).

1. Introduction

Disruptions, the fast accidental losses of the plasma current and stored energy in tokamaks, are critical issues for reactor-scale fusion facilities like ITER and present a risk of severe damage to vital plant components and structures. Although the rate of disruptions can be successively minimized by developing appropriate techniques to operate tokamaks, they may never be completely avoidable [1,2]. This has led to an international effort to study mitigation techniques such as massive gas injection (MGI) [3–6].

Disruption mitigation is crucial, especially in larger tokamaks like JET with its ITER-like Wall (ILW – Be and W used as plasma-facing material in the main chamber and divertor) [7] which can experience considerable damage during unmitigated disruptions. The absence of radiating impurities due to the ILW can have severe implications such as excessively high heat loads on the plasma facing components (PFC), leading to melting events, as well as high forces on the vacuum vessel and the supporting structure. To minimize these effects a MGI valve and corresponding auxiliary equipment, originally designed for MGI studies, has been integrated

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[1] See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA FEC 2012, San Diego, USA.

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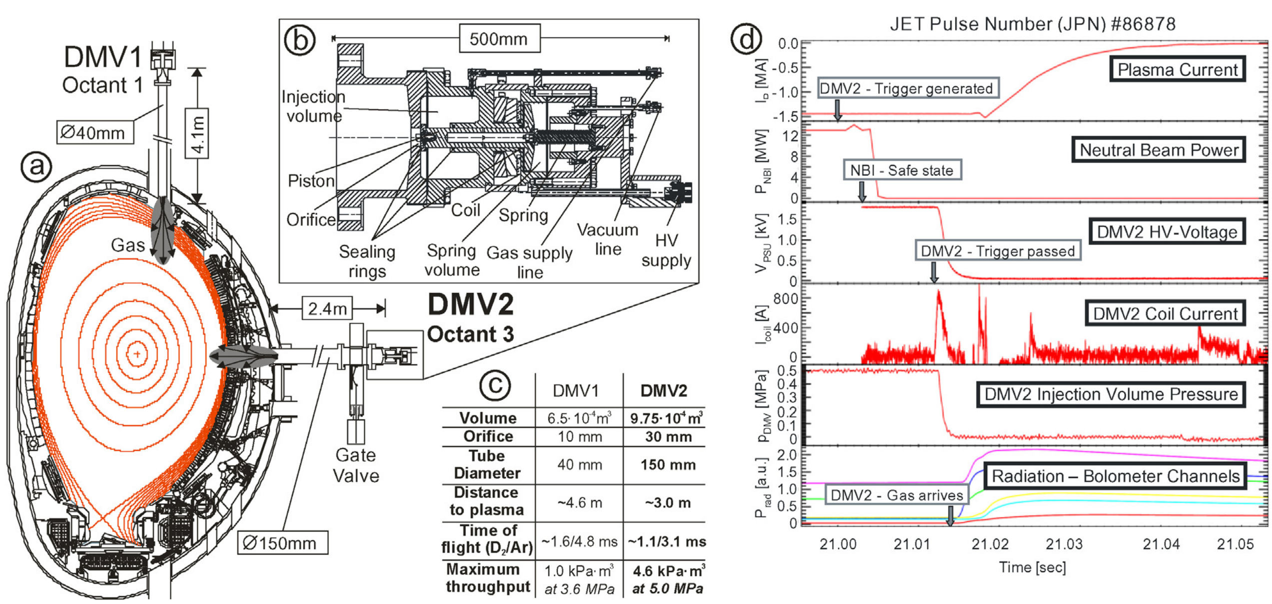
into the JET machine protection system [8,9]. With the utilization of this valve the first Disruption Mitigation System (DMS) was established at JET which could reduce high vessel forces and local heat loads on PFCs by increasing the radiated energy up to 100% of the initially stored energy [10].

Plasma operation without DMS has been generally restricted to plasma currents up to 2 MA and total plasma energy (poloidal magnetic + kinetic) below 5 MJ. As a consequence, the majority of JET pulses nowadays require the DMS; the requirements for the reliability and the availability of the existing system resulted into the need for a new DMS. This new system includes a new MGI valve and corresponding auxiliary systems which have been designed and integrated into the JET environment, primarily to provide redundancy to the original DMS during deuterium–deuterium operation. Furthermore it allows a wider range of MGI experiments due to significant performance improvement compared to the original system. It incorporates experimental features such as six separate gas feeding lines, for example Ar, Ne, Kr, D_2, N_2 and mixtures of these, similar to the original DMS (three lines), but is also able to deliver five times more gas in two thirds of the time due to a shorter and wider gas delivery tube. The new DMS has been specifically designed to operate reliably under harsh nuclear conditions and to act as a reliable machine protection system during the planned deuterium–tritium (DT) campaign at JET. This article presents the new DMS at JET, which consists of a fast high pressure eddy current driven valve, the disruption mitigation valve (DMV), an all metal gate valve compatible with high pressure injections, a high voltage power supply and an all metal gas handling system providing six separate supply lines for flammable and noble gases.

2. The Disruption Mitigation Systems at JET

The two Disruption Mitigation Systems at JET consist of two fast eddy current driven valves called DMV1 and the new DMV2 located in two different JET octants (toroidally 90° apart) and poloidal positions, as indicated in Fig. 1a. DMV1 is mounted on a probe drive on top of JET in octant 1 and is connected via a 4.1 m long gas delivery tube to the vacuum vessel (diameter 40 mm, distance to separatrix ~0.5 m). DMV1 and the attached delivery tube can be driven through a gate valve with the help of the probe drive infrastructure and can be retracted if necessary to seal off the primary Torus vacuum. The new valve (DMV2), shown in Fig. 1b, is located in octant 3 on a horizontal port with a wider and shorter gas guiding tube (length 2.4 m, diameter 150 mm, distance to separatrix ~0.6 m). For reliability purposes, no moving parts are present within the primary Torus vacuum in the new system, fulfilling containment requirements for DT operation. The injected gas passes a special type of gate valve which is designed to withstand higher pressures and to optimize the through flow. In general, the simplification of the setup is one of the key features to assure a reliable DMS operation. Both valves are activated by individual HV power supplies. These power supplies are triggered by the JET Pulse Termination Network (PTN) utilizing a direct fiber connection [9] leading to the desired gas release. A typical MGI sequence applying DMV2 is shown in Fig. 1. In closed loop operation, once the potential for a disruption arises (typically when the amplitude of a locked $n = 1$ mode or an excursion of the loop voltage, indicating the start of the CQ, is detected) or is deliberately induced for disruption studies, a trigger signal is generated, warning first all auxiliary heating and diagnostic systems of potential damage from high vacuum pressures. When these systems are in a safe state, the trigger is passed to the DMS high voltage power supply which induces a current into the DMV coil causing the valve to open and to inject the gas into the plasma (within 5 ms). As a result, the radiation increases due to the interaction between the injected gas and the plasma, which effectively reduces the plasma energy. Ideally this is achieved before the plasma becomes vertically unstable and hits the wall causing excessive heat loads on the PFCs. The gas for either machine protection or MGI experiments is provided by individual gas handling systems (GHS). Both of these are equipped with the possibility to load pure gases or gas mixtures and to remove or change these gases automatically in between plasma pulses upon request of the main JET control system. As a pressurized high voltage system, the DMS has to provide operational safety aspects as well as personnel safety. It is therefore equipped with various passive mechanical safety features, software and hardware interlocks and monitoring equipment



	DMV1	DMV2
Volume	$6.5\cdot10^{-4}$ m³	$9.75\cdot10^{-4}$ m³
Orifice	10 mm	30 mm
Tube Diameter	40 mm	150 mm
Distance to plasma	~4.6 m	~3.0 m
Time of flight (D_2/Ar)	~1.6/4.8 ms	~1.1/3.1 ms
Maximum throughput	1.0 kPa·m³ at 3.6 MPa	4.6 kPa·m³ at 5.0 MPa

Fig. 1. (a) Poloidal cut of JET presenting the JET DMS. The two disruption mitigation valves (DMV) are projected into the same poloidal plane. Their physical positions are on top of the machine in octant 1 (DMV1) and at a horizontal position in octant 3 (DMV2). Both systems are located 90° toroidally apart. (b) Technical drawing of the new DMV (DMV2). (c) Characteristic properties of the two DMS. (d) Typical DMV2 sequence (JET Pulse Number (JPN) #86878, $B_t = 1.5$ T, $I_P = 1.5$ MA, Auxiliary heating: 14 MW NBI, DMV request time: 21.0 s, Total injected gas: 0.5 kPa m³ of 10% argon and 90% deuterium mixture, Time of flight: ~1.5 ms, total radiated energy fraction is about 92% (not considering radiation asymmetry effects).

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