Design of the Massive Gas Injection system for JT-60SA

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1. Abstract

Disruption mitigation is one of the main research topics on the way to ITER and future Tokamak fusion power plants. Therefore, extensive studies have to be carried out on large Tokamaks to understand the physics and to develop the necessary technologies. JT-60SA, which will go into operation in 2020, will be a primary machine for this research. It will be equipped with a Massive Gas Injection (MGI) system to conduct disruption mitigation experiments in the first research phases. This MGI system will consist of two fast valves with integrated reservoirs (833 cm³, 7.5 MPa, 6247 Pa*m³, $1.5*10^{24}$ particles), which will be installed inside the vacuum vessel behind the stabilizing plate in sectors P09 and P18. Due to their location inside the vacuum vessel, the valves must be compatible with in-vessel conditions (magnetic field, elevated temperature, radiation and vacuum). Hence, a spring-driven valve with piezoelectric actuation was chosen as design basis. It is foreseen to inject a large variety of different noble gases and gas mixtures with H_2/D_2. CFD calculations were carried out to evaluate the gas flow from the valves into the vacuum vessel. This paper presents the detailed design of the MGI valves, a description of the in-vessel setup and the results of the CFD analysis.

2. MGI valve

The JT-60SA MGI valves (Fig. 1) are based on the ASDEX Upgrade spring-driven valve design [1]. The gas reservoir was enlarged to 833 cm³ and fitted for gas pressures of up to 7.5 MPa. This allows the injection of up to 6247 Pa*m³ or $1.5*10^{24}$ particles. The two MGI valves which will be installed inside the JT-60SA vacuum vessel, will hence be able to inject up to 12.5 kPa*m³ per discharge. For a successful disruption mitigation in a Tokamak the size of JT-60SA a minimal gas amount of 400 Pa*m³ [2] is required. The mitigation gas will be a mixture of 90 % H_2 or D_2 and 10 % noble gas. This mixture has shown on JET to be the best compromise between mitigation efficiency and avoidance of runaway electron generation. Since JT-60SA has a safety limit for its hydrogen inventory inside the vacuum vessel of 100 kPa*m³, 8 full MGI injections can be performed before the cryogenic pump reaches the safety limit.

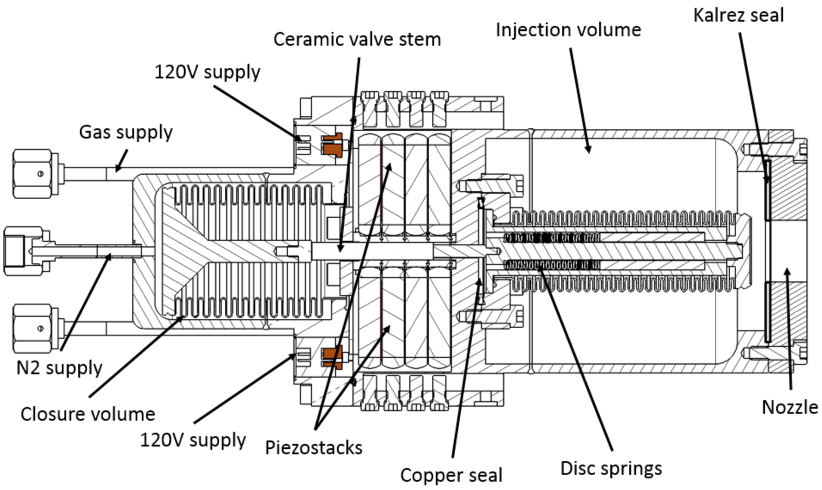

Figure 1: Cross-section of the JT-60SA MGI valve with annotations of the functional components

The MGI valves will be installed behind the stabilizing baffle plate to shield them against the plasma's thermal radiation while still being as close as possible to the plasma edge. The gas will be injected through holes in the baffle plate. Installation locations are in sector P09 and P18 to reach the maximal toroidal distance between both injection locations. This allows the reduction of radiation asymmetries [3]. Poloidally, the valves will be located in the upper oblique position. At this location, the injection holes are about 10 cm away from the separatrix (Fig. 2). This is the shortest distance that can be found between the stabilizing plate and the plasma edge, thus minimizing the time of flight of the mitigation gas. Furthermore, the q = 2 surface is also close to the injection location.

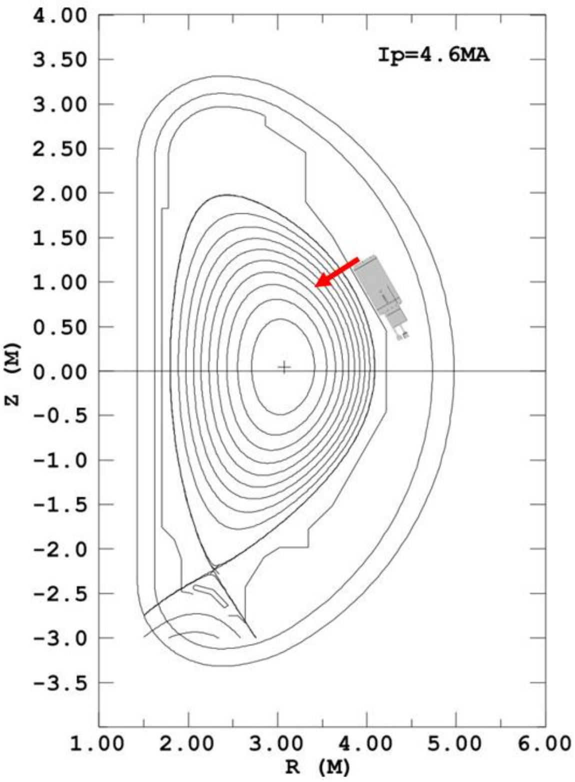

Figure 2:Poloidal cross-section of the vacuum vessel with MGI installation location and flux surfaces

To evaluate the valves performance, CFD simulations were performed using ANSYS Fluent. The gas reservoir, the valve piston and the nozzle are cylindrical and thus axisymmetric. Thus, these components were modelled in a 2D surface model representing half of the reservoir cross-section. This simplified model was preferred over the full 3D model to save computing time. The model was extended beyond the valve nozzle by 27 cm * 30 cm of vacuum space to investigate the expansion of the gas plume. The surface was meshed with a regular square mesh incorporating cells with 1.6 mm length.

A density based solver with first order implicit formulation for the transient equations was used with a fixed time step size of $5*10^{-7}$ s and 20000 time steps to achieve a simulated duration of 10 ms.

The efficiency of the MGI valve is determined by the amount of gas that can be delivered on a certain time scale. The gas assimilation into the plasma works well as long as the plasma can provide the ionisation temperature of the impurities. Cooling begins when the gas reaches the plasma. Hence, the gas has to be delivered within milliseconds. The JT-60SA MGI valve can deliver between 79 % and 94 % of its gas inventory within 10 ms depending on the gas mixture (Fig. 3 left). The necessary 400 Pa*m³ is injected within the first millisecond after the piston starts moving in the case of 7.5 MPa initial gas pressure in the reservoir (Fig. 3 right).

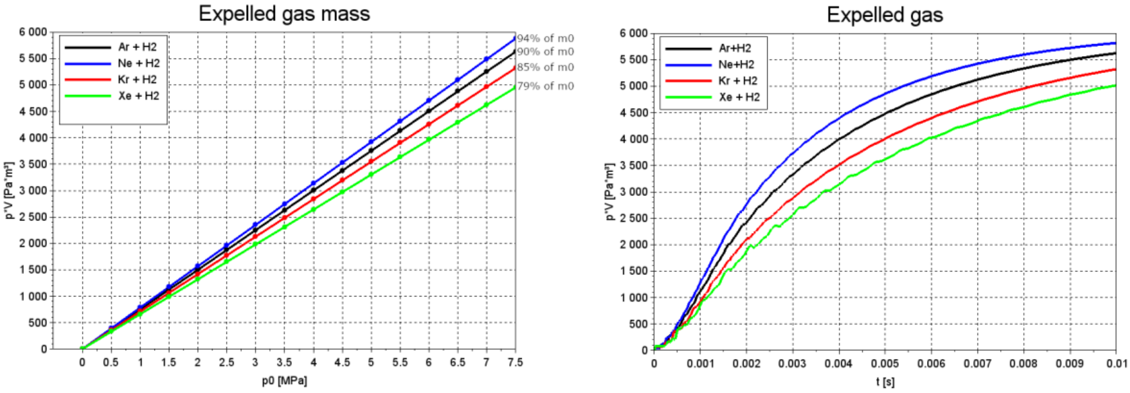

Figure 3: Expelled gas mass of for different gas mixtures for different initial gas pressures (left) and the amount of expelled gas over time for the four different gas mixtures (right)

When exiting the nozzle and the subsequent hole in the stabilizing plate, the gas forms a plume in the vacuum vessel. This plume expands until it reaches the scrape-off layer where it begins to ionize. The density of the gas plume was investigated at the distance from the stabilizing plate where the separatrix would be. Ionization is assumed to be negligible up to the separatrix.

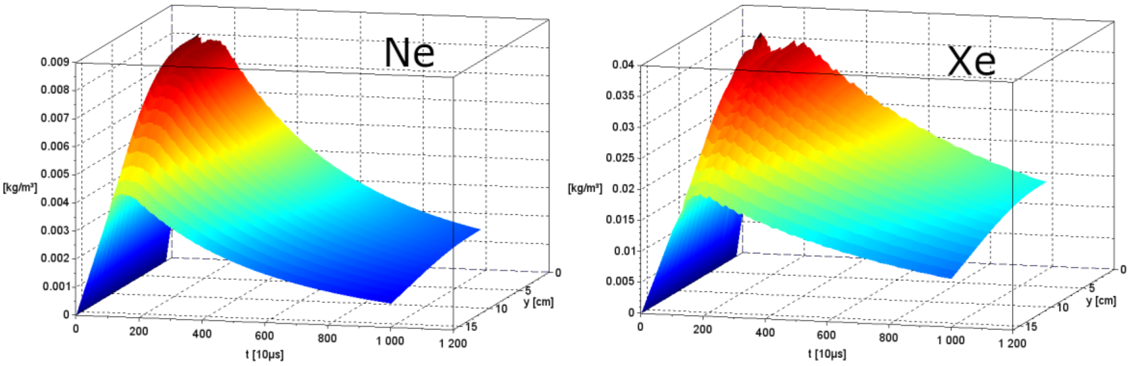

Figure 4: Evolution of the density profile over the plume radius y at the separatrix for the Ne and Xe gas mixtures

The density at the separatrix rises quickly and reaches its peak value (between 8 g/m^3 and 35 g/m^3) after about 1 ms. Following this peak, the residual gas is delivered leading to a slow decrease of density to values between 19 % and 40 % of the peak value depending on the gas mixture. The radius of the gas plume at the separatrix, beyond which the density is below 10 % of the peak value, is between 23 cm for the Ne mixture and 25 cm for the Xe mixture after 1 ms. After 10 ms, the radius has decreased to 21 cm for the Ne mixture and 24 cm for the Xe mixture.

3. Summary

A new MGI system for JT-60SA has been designed. It will consist of two in-vessel valves, each containing up to 6247 Pa*m^3 of mitigation gas (90 % H_2 or D_2 with 10 % noble gas). These valves will be installed 180° toroidally apart in upper oblique position close to the separatrix. The MGI valves can inject up to 94 % of their inventory within 10 ms. The resulting gas plume in the vacuum vessel reaches a density of up to 35 g/m^3 at its centre and has a radius of about 25 cm at the separatrix.

4. References

[1] M. Dibon et al. Spring-driven high speed valve for massive gas injection in tokamaks, Rev Sci Instrum. 2017, 88(3):033508. https://doi.org/10.1063/1.4978805

[2] M. Lehnen et al. Disruption mitigation by massive gas injection in JET, Nucl. Fusion 2011, 51 123010. https://doi.org/10.1088/0029-5515/51/12/123010

[3] M. Lehnen et al. Radiation asymmetries during the thermal quench of massive gas injection disruptions in JET, Nucl. Fusion 2015, 55 123027. https://doi.org/10.1088/0029-5515/55/12/123027

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