Capabilities of the Massive Gas Injection System on TCV

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Abstract

Disruption handling remains a significant issue for ITER and future reactors. Disruptive scenarios are created and studied using a Massive Gas Injection (MGI) system on TCV. The goal of this work was to classify the MGI exhaust for analysis and modelling of neutral gas interaction with the plasma. Benchtop experiments were performed and demonstrated the dependence of the number of neutral particles injected on reservoir pressure, number of valves used, opening time and gas type. The injected particle rates were found to be between 1-30 x 10^{19} particles/ms. Total pressure profiles were obtained for Helium at 3 cm from the exhaust with the centreline pressure of 221 Pa and divergence of 58.7°. MGI injections on TCV were used to infer the neutral gas velocity to be in the range $428 - 937$ m/s.

Introduction

A disruption is a rapid loss in plasma confinement that on TCV often occurs on millisecond timescales through numerous pathways, such as adverse neoclassical tearing modes (NTMs), edge radiation instabilities, etc. With high stored energies, disruptions are able to generate severe damage to in-vessel components. Therefore, disruption handling is critical in the safe operation of larger machines, such as ITER, as well as future reactors.

Disruptions typically begin with a thermal quench (TQ), during which the plasma thermal energy is conducted to the divertor or plasma facing components (PFCs) leaving a cold resistive plasma that then causes a current quench (CQ). The TQ timescales are much lower than inductive timescales, so the toroidal current remains approximately constant across the TQ. This leads to an increase in the inductive electric field to conserve the current. If the electric field exceeds the Connor-Hastie threshold, electrons can be accelerated to relativistic velocities, termed runaway electrons (REs). If destabilised, a stream of REs can leave the confined plasma core causing localised heat loads upon impact with the potential to cause severe damage [1].

A Massive gas injection (MGI) system has been developed on TCV, enabling the investigation of impurity transport [2], disruption avoidance through the creation of disruptive scenarios [3], disruption mitigation and secondary Deuterium injections for impurity flushing in RE beams through controlled injection of an additional 5% to 5000% of the plasma bulk.

The goal of this study is to classify the MGI exhaust for future analysis and modelling of injected gas interaction with plasma. This classification was performed through benchtop and TCV experiments, involving measurements of the number of injected particles, total pressure profiles and average exhaust gas velocity.

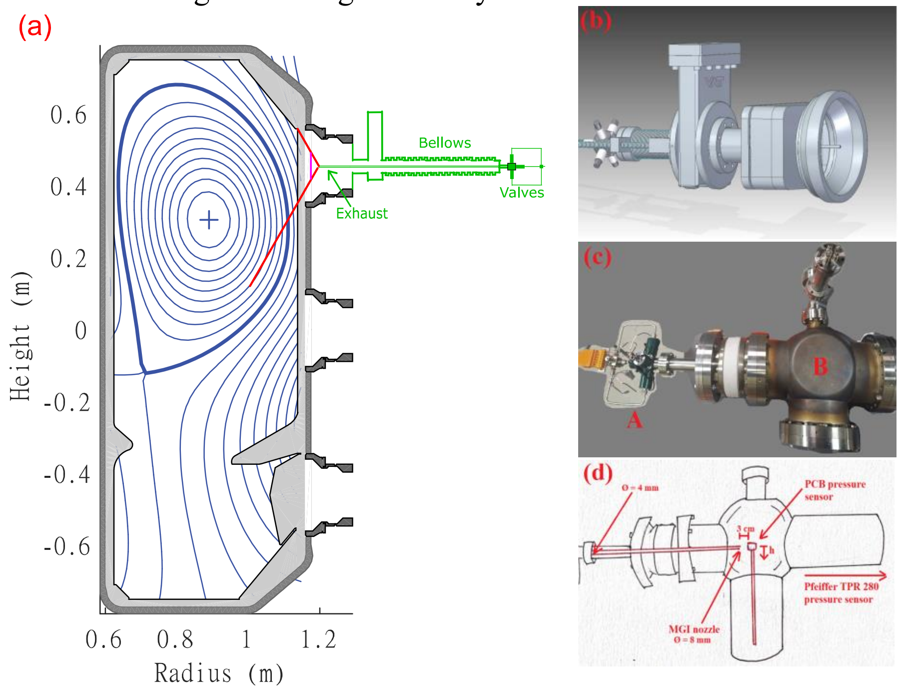

Figure 1.
(a) MGI exhaust in a TCV cross-section
(b) MGI geometry
(c) Experiment layout: A – MGI B - vacuum chamber
(d) Sketch of the insides of the vacuum chamber

System Description

The MGI system consists of 5 fast actuating piezoelectric Parker series 9 valves [4] with opening and closing times of less than 0.3 ms. Multiple power supplies and gas lines allow the injection of different gas species and staggered injections during a single discharge. The design includes a bellows to vary the distance between the MGI exhaust and the plasma, allowing variation in gas dispersion and velocity. The piezoelectric valves open through the generation of a local magnetic field and are thus sensitive to the Tokamak's magnetic field. Soft iron and mu metal are used to reduce the field from 1.5 T to 1 mT, effectively shielding them from TCV. Figures 1 (a) and (b) show the MGI geometry together with its location and injection cone (measured in this study) on TCV.

Experiment description

The experiment consists of the MGI system, a vacuum chamber, dynamic pressure gauge (PCB ICP® 113B28 [5]) and static pressure gauge (Pfeiffer TPR® 280 [6]) (Fig.1 (c), (d)). Dependent variables in the experiment were the reservoir pressure, number of valves in operation, opening duration, gas species and PCB probe position (h in Fig.1 (d)).

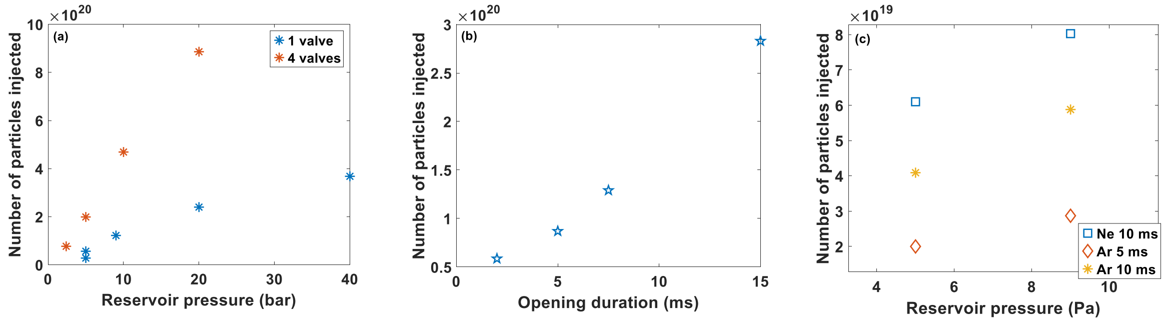

Figure 2. Number of particles injected (a) He for 5 ms opening time; (b) Ne, 1 valve 20 bar reservoir pressure; (c) Ne and Ar, 1 valve

An investigation of the number of particles injected was performed for a range of reservoir pressures between 1 and 40 bar, valve opening durations and for 3 gas species: He, Ne and, Ar. The experiments were performed by varying one of the dependent variables whilst keeping the others constant.

The pressure profile experiments were limited to a reservoir pressure of 20 bar due to PCB/amplifier sensitivity and then only to the first ms due to sensor dynamics limitations. Here, only the probe position was a dependent variable.

The gas velocity was inferred from the opening time of the valve (measured by the current and voltage trace of the piezoelectric valves) to an increase in plasma emission measured by the AXUV diodes in the adjacent sector. This is an average velocity between the valve throat and the plasma separatrix and it was obtained for a range of reservoir pressures and gas species.

Experimental results and discussion

Static pressure measurements from Pfeiffer sensor were used to infer injection rates between 1-30 x 10^{19} particles/ms. The injected quantity was found proportional to number of valves used, valve opening durations, reservoir pressures but dependent on the gas used (Fig. 2).

A PCB pressure sensor was used to measure pressure profiles for Helium injection at 20 bar reservoir pressure and 3 cm from the MGI exhaust. The profile was found to follow the normal distribution:

$$P = P_{max} e^{-\left(\frac{h}{h_0}\right)^2}, P_{max} = 221\ Pa,\ h_0 = 2.47\ cm.$$

Where P is the total pressure and h is the distance from the centreline to the pressure sensor. Horizontal error bars on figure 3 (a) show PCB size and positioning uncertainties. It is possible to approximate the gas cone opening angle

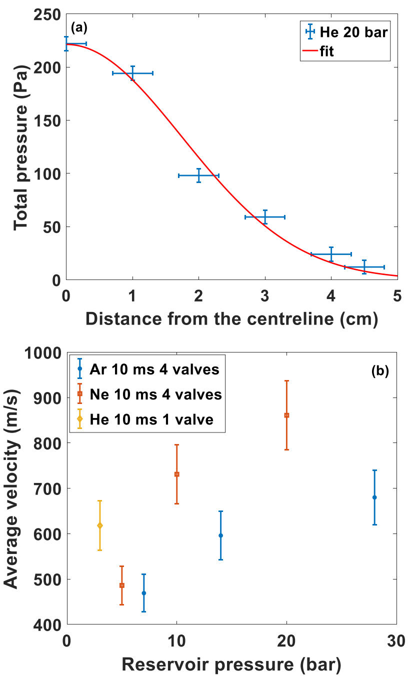

Figure 3. (a) Pressure profile of He at 20 bar reservoir pressure (b) Velocity dependence on reservoir pressure

from the distance between the PCB and the exhaust (Fig.1 (d)), using twice the standard deviation of the normal distribution: $\theta = \tan^{-1}\frac{2h_0\ cm}{3\ cm} = 58.7°$. Assuming a linear gas expansion, the opening angle may be used to predict the expansion of He gas at 20 bar reservoir pressure in the TCV chamber (red cone in Fig.1 (a)). This assumption, together with its extension to other gas species and reservoir pressures, will be investigated in future works. The position of the measured pressure profile (purple line in Fig.1 (a)) suggests that these should measure the pressure profiles further away from the exhaust.

The average injected gas velocity for Argon, Neon and Helium gases for a range of valves numbers, reservoir pressures are shown in figure 3 (b) and falls in the range of $428 - 937$ m/s. Velocities increased with reservoir pressure and decreasing atomic number. These inferences may then be used to model the neutral flow and estimating the neutral gas penetration depth.

Conclusions

Benchtop experiments provided the total pressure profile of He 20 bar reservoir pressure at 3 cm from the exhaust with the centreline pressure of 221 Pa and divergence of $58.7°$. The injected particle rate was found to be 1-30 x 10^{19} particles/ms. Dependance of the number of particles injected observed on reservoir pressure, number of valves used, valve opening duration and gas type. Average gas velocity inferred to be in the range of $428 - 937$ m/s. Obtained experimental results will be used for the future modelling and extrapolation.

Acknowledgements

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