Fusion Engineering and Design 87 (2012) 813–821

Contents lists available at SciVerse ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

A description of the ITER's gas injection systems and current R&D activities☆

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ARTICLE INFO

Article history:
Available online 8 March 2012

Keywords:
ITER
Gas injection system
R&D
GIS response time
Magnetic shield design

ABSTRACT

The gas injection system (GIS) is an indispensable part of ITER fueling system. It deliveries the necessary gas species from tritium plant to vacuum vessel, pellet injection system or neutral beam for plasma operation and fusion power shutdown. In this paper, the current design status of GIS, including the previous design changes, is briefly described. As the GIS design justification and support, the experimental study on GIS response time is illustrated. The factors delayed the GIS response time are identified, and two kinds of control mode are proved to be effective for improving the GIS response time. The exploration on magnetic shield design shows the discrepancy of shielding performance occurs in the case of the paralleling external magnetic field to the sample cylinder. These R&D works prove the design feasibility in some ways, and support possible solutions for design challenges as alternative design options.

1. Introduction

ITER will be the first experimental reactor to produce a 'burning' deuterium–tritium plasma [1]. The mixture gases with proportional deuterium and tritium as the fuel of 'burning' plasma will be provided by the tritrium plant (TP) and injected into the torus by dedicated fueling system. The gas injection system (GIS) is a major part of the fueling system, it shall provide the fuel gases for plasma initiation, density control and fuel replenishment. Besides that, it also needs to provide the functions of impurity gases injection for radiative cooling and fusion power shut down, supply the working gases for pellet injection system (PIS), neutral beam (NB) and diagnostic neutral beam (DNB) injector and wall conditioning.

The GIS, in a simple word, is an actuator to inject the specified gas species and throughput at given time slot following the commands from plasma control system (PCS) via COntrol, Data Access and Communication (CODAC) system to meet ITER project requirement.

The GIS and its technical challenges associated have been introduced in many presentations [2–5]. And the conceptual design was complemented and changed gradually with the clarifying of physics requirements, boundaries and interfaces. Up to now, the conceptual design of GIS, incorporated previous design changes and corresponding R&D, has been completed.

In this paper, the overall description of GIS is briefly presented in Section 2. And Section 3 focuses on some R&D activities, which supports the justification of design feasibility in some ways and provide the potential solutions for design challenging associated.

2. Brief description of gas injection system

The GIS consists of gas distribution system (GDS), gas fueling system (GFS) and fusion power shutdown system (FPSS).

GFS shall perform the functions of delivering fuel particles (H2, D2 and DT) at average and peak throughputs of 200 Pa m^3/s and 400 Pa m^3/s, respectively together with PIS or impurity gases (Ne, Ar and N_2) at average and peak throughputs of 10 Pa m^3/s and 100 Pa m^3/s into the ITER's vacuum vessel (VV) at specified gas injection positions via the local control system (LCS). And the response time (to 63%) is required to be less than 1 s for the case of 20 Pa m^3/s throughput for plasma fueling and 5 Pa m^3/s throughput for impurity gas injection.

In current design, there are four gas injection positions in the upper port level and six gas injection positions in the divertor level, as shown in Fig. 1.

The upper port injections are envisaged mainly for plasma fueling, as well as vehicles for He ash removal, coupling improvement of RF heating systems and possible auxiliary control for divertor protection during burning plasma operation [4].

The upper port injection points are located in the gaps between the blankets in the toroidal direction at ports 3, 6, 10 and 14 to minimize the conflict with main chamber diagnostics and EC antenna. In order to achieve an optimum toroidal uniformity, the fuel gas shall be injected simultaneously at these four injection points and released at the multi-point injection along the poloidal

☆ The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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doi:10.1016/j.fusengdes.2012.02.029

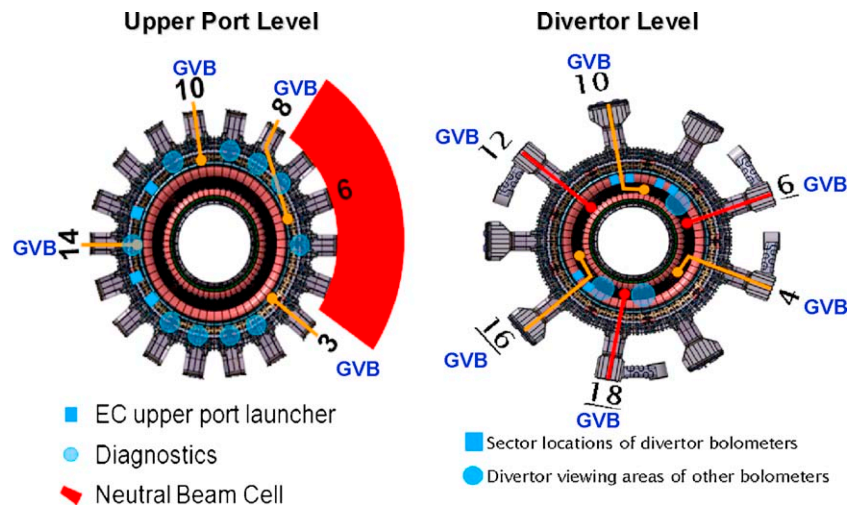

Fig. 1. Location of gas valve boxes (GVBs) and injection point in upper port level (left) and divertor level (right).

direction between the upper port and the equatorial port. Thereafter it reaches the plasma through toroidal/poloidal gaps in the ~50 cm thick blanket modules.

The divertor injection points are envisaged mainly for extrinsic seeding of impurities to achieve detachment control through volumetric radiative cooling. The six gas injection positions are located in ports 3, 6, 9, 12, 15 and 18. They are uniformly distributed along the torus to improve toroidal uniformity of divertor plasma radiation and provide system redundancy in the case of injector failure [4]. At present design, the gas injection point is positioned between the divertor cassette and the VV wall. And the gas can be released in the space under the dome and through the gaps between the divertor cassettes.

The gas valve boxes (GVBs) are crucial parts of GFS, they provide the functions of gas species and throughput control, as well as the measurement of the gas pressure, flow rate and temperature. The GVB is located in the port cell nearest to its corresponding gas injection point to have the shortest gas injection line and achieve the quick response time. In current design, the GVBs in upper level are located in ports 3, 8, 10 and 14, and the GVBs in divertor level are located in ports 4, 6, 10, 12, 16 and 18, respectively. The gas injection line will penetrate the VV at the same port with its GVB and route to the gas injection position along the VV wall. Considering the tritium gas delivery, both GVBs and gas injection lines out of the VV have double containments.

The GVB in GFS is identical wherever it lies in upper port level or divertor level at the current design. Its flow diagram can be found in many ITER fueling review presentations [2]. It comprises six identical gas flow control channels and one pumping and flushing line. Each flow channel is connected to its respective gas inlet supply line and routed through a mass flow meter, gas dosing valve and 0.2 MPa isolation valve before connecting to a common gas injection manifold. The supply pressure of each channel and delivery pressure in the common manifold are measured by pressure transducers. The temperature is also measured on all delivery lines to provide temperature compensation of the mass flow meters. The pumping and flushing line is connected to the common injection manifold via a 0.2 MPa gas by-pass valve. A dedicated injection line connected to this manifold exits the valve box via a 0.2 MPa isolation valve.

The physical arrangement of components inside GVB is designed from a space reservation perspective because the tritium compatible control valves met ITER GIS requirements are still challenging. 1/2-in. 316L stainless steel tube and Vacuum Coupling Radius sealing are preferred for the components' maintainability. The gas injection manifold is designed as small as possible to eliminate its effect on GIS response time. The total space of $\varnothing 0.8\,\mathrm{m} \times 0.9\,\mathrm{m}$ for GVB is roughly estimated if components' installation, compressed gas lines or cables routing and possible signal conditioning circuits are taken into account.

Magnetic shield for GVB is indispensable because of high stray static magnetic field (1500–2000 Gs) at GVB location. And it can also provide the secondary containment for tritium. The shape of magnetic shield is like bell jar. The gas supply manifold, gas injection lines and other service feed-throughs will penetrate the magnetic shield from the bottom. From the extrapolation of current R&D, which will be described in Section 3 detailedly, the thickness of magnetic shield made by soft iron will be 20 cm. It has an amazing deadweight (over 7 tons) and is a big load on the side wall of port cells. In order to improve such situation, shielding the magnet sensitive components only and replacing the secondary containment by standard glove box are expected in the future design, but that lies on the hazard and operability (HAZOP) analysis and space reservation.

The gas injection line has double containments outside the VV. 1/2-in. 316L stainless steel tube is centered in 1-in. tube which forms the secondary containment. Suitable design of bellows and bending tail can eliminate the deformation caused by VV displacement. The penetration considering electrical insulation is designed and its structure in divertor level is more complex than that in upper port level [6].

GDS is responsible for delivering the different gas species from tritium plant to the specified GVBs or to the injector of NB&DNB directly. It has two manifolds (a gas distribution manifold and a dedicated manifold) and GVBs for PIS.

These two manifolds have the same configuration, gas supply lines and evacuation line enclosed in a guard line, for safety operation of tritium handling. And the pumping, purging and back filling operations are also provided by the tritium plant.

The gas distribution manifold has horseshoe shape along the bio-shield at upper and divertor level [2–6]. It contains six individual gas supply lines for H_2/D_2, H_2, T_2, 4He/3He, N_2/Ne and Ar. The gas supply in hydrogenic gas lines shall be maintained under one atmosphere from safety point of view. Each gas supply line is sized following the ASME B36 S10 standard to provide a minimum pressure drop at the maximum flow rate and to minimize the tritium inventory of the system. The manifold cross section has been designed elaborately at the moment to avoid the interference of pipe junction from horizontal and vertical direction in manifold routing, as well as to reserve enough welding space for installation and maintenance [6], as shown in Fig. 2. The gas