Fusion Engineering and Design 88 (2013) 831–834

Contents lists available at ScienceDirect

Fusion Engineering and Design

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

Progress in the design of ITER front-end vacuum instrumentation and controls

Bastien Boussier[a,*], Stephen Bryan[a], Matthias Dremel[a], Jean-Marc Fourneron[a], Christian Mayaux[a], Robert Pearce[a], Peter Saunders[b], Dhananjay Mokashi[c], Jean-Marc Poncet[d], Pantxo Diribarne[d]

[a] ITER Organisation, Route de Vinon, 13115 Saint-Paul-lez-Durance, France
[b] Babcock International Group Plc, The Manor Court, Chilton, Harwell, Oxfordshire OX11 0RN, United Kingdom
[c] TATA Consultancy Services, 1 Mangaldas Road, Pune 411001, Maharashtra, India
[d] Service des Basses Températures, CEA Grenoble, 17, rue des Martyrs, 38054 Grenoble Cedex 9, France

ARTICLE INFO

Article history:
Received 14 September 2012
Received in revised form
21 December 2012
Accepted 8 February 2013
Available online 7 March 2013

Keywords:
ITER
Vacuum
Instrumentation
Controls

ABSTRACT

The ITER vacuum system will be one of the largest and most complex vacuum systems ever to be built. Extensive instrumentation and controls are being developed to satisfy the stringent vacuum processes necessary for the successful and safe operation of the ITER Tokamak. The complexity and deep integration of the vacuum systems within the ITER machine presents a challenge to implement all of the controls necessary for reliable operation. Several thousand valves and sensors have to be implemented within the harsh environmental conditions of the Tokamak vicinity, and require engineering of instrumentation and controls with remote electronics solutions.

In this paper the status of the design of field end vacuum controls and instrumentation for the ITER vacuum systems is described. Details of the progress on selection of sensors and actuator technologies are given herein and solutions for remote device operation, including those for cryogenic devices, are described together with necessary local shielding.

1. Introduction

The ITER vacuum system is devoted to pumping out the vacuum volumes of the tokamak, either transiently or in steady-state, so as to establish, and to maintain, the necessary vacuum conditions for ITER operation. It allows each pumped component to function in accordance with its design and safety requirements, and to operate in conjunction with other systems to enable realization of the ITER plasma discharge scenarios.

Such extended system is composed of the core pumping of the fuel cycle responsible for the evacuation of vacuum vessel and directly coupled volumes – such as neutral beam injectors and primary vacuum extended diagnostics – and of all auxiliary systems for plasma heating RF waveguide pumping, type one diagnostics systems pumping and interspaces volume management. All systems additionally feature venting and purging as well as leak detection and localization functionalities.

Control requirement and integration solutions are being optimized for each system in accordance with constrains and system criticality to obtain the best value engineered systems fulfilling the stringent ITER requirements (Fig. 1).

2. Environmental conditions and integration

2.1. Magnetic field conditions

Superconducting tokamaks such as ITER do not feature a magnetic core returning the magnetic fields of the inductive loop and therefore present extended and intense magnetic fields in the machine vicinity. Such fields, mainly generated form the central solenoid and poloidal coils, affect vacuum equipment throughout all of the Instrumentation and Control (I&C) chain. Pumps, sensors, pre-actuators, controllers and electrical equipment are affected and need careful selection and shielding to guarantee their correct operation.

Vacuum gauging located the closest to the machine just outside the bioshield will be subject to fields up to 0.4 T. Equipment located in the port cells, such as service vacuum system distribution boxes for containment interspaces control and cold valve boxes providing the supercritical helium for correct cryopumps operation will need to withstand above 0.1 T, and equipment located in the galleries or further away will still have to operate up 40 mT.

2.2. Radiation conditions and I&C integration

The ITER vacuum system is mainly integrated outside of the bioshield and is therefore not primarily affected by the direct plasma radiation, although specific areas such as the neutral beam

* Corresponding author. Tel.: +33 4 42 17 63 32.
E-mail address: Bastien.boussier@iter.org (B. Boussier).

0920-3796/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fusengdes.2013.02.038

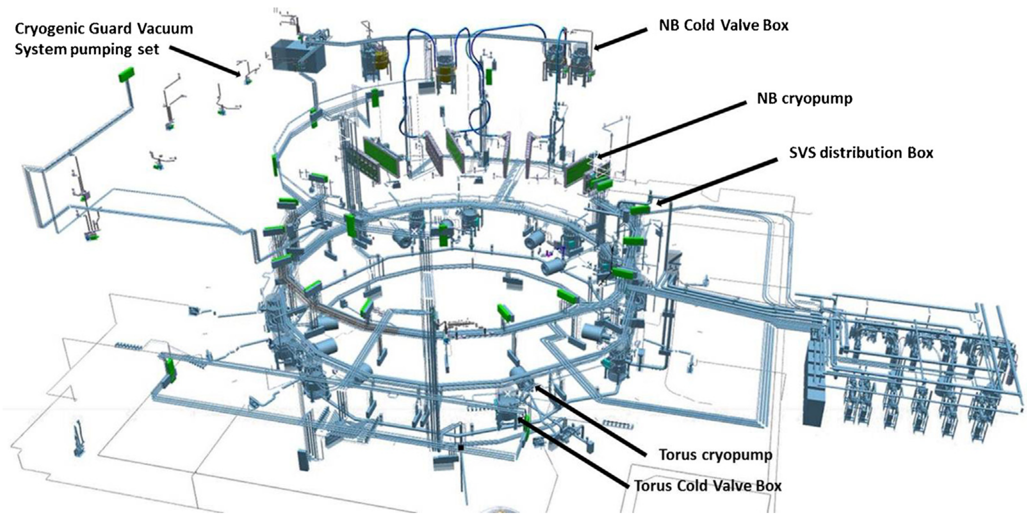

Fig. 1. Vacuum systems overview.

cell still represent high challenges with significant shine through the port openings. The main distributed source of radiation affecting the vacuum system originates from the activated water cooling system of the primary heat transfer system. Due to the intense neutron bombardment on the cooling water on the plasma first wall, oxygen of the water transmutes into short lived nitrogen isotopes providing intense gamma radiation (6.3 MeV), associated to significant neutron fluencies [5].

Building shielding around primary heat transfer water-cooling systems has been recently increased, not only to protect the people and environment, but to ease the integration of instrumentation and control equipment within the tokamak building. Estimated integrated radiation dose within all gallery areas has been decreased to 100 Gy level, to limit the need for development of specific radiation hard electronic in most instances. It is estimated that only minimal shielding will be needed to use off the shelf equipment under these conditions. A specific policy for electrical and electronic equipment has been developed and implemented to guide selection and qualification of I&C equipment to be installed in the tokamak building.

Divertor cooling water pipes are routed directly through lower port cells, and could not be shielded to prevent high doses to local equipment. Cryogenic cold valve boxes, service vacuum system distribution boxes, diagnostics pumping turbo-molecular pumps and various instrumentation will therefore be exposed to up to near 10^6 Gy integrated doses over the lifetime of the machine (Fig. 2).

3. Cryopumping system control solutions

The high vacuum pumping of the tokamak, cryostat and neutral beam injectors is operated by means of custom build supercritical helium cooled charcoal coated cryopumps. These cryopumps and corresponding controls are located in port cells and NB cells, and are therefore exposed to demanding environmental conditions requiring special care in implementation. Magnetic fields up to 0.4 T and radiation levels above 10^6 Gy range are expected for part of these field end instruments.

3.1. Vacuum gauging and analytic devices

Vacuum gauges and analytic instruments (Residual Gas Analysers) located in port cells are necessary for correct cryopump operation in order to control the divertor pressure and throughputs, and to balance cryopump gas loading to comply with operational and safety limits.

Due to the surrounding conditions, radiation tolerant transducers heads (i.e. no active electronic) will be used and magnetic shielding will be implemented where necessary for device operation. Inverted Magnetron Gauge transducer heads with specific magnets and careful alignment to the surrounding induction field are considered appropriate for implementation on the main volumes due to their proven robustness and off-the shelf fully remote controlled solutions from various manufacturers. Controllers can therefore be implemented within standard size control cubicle located in the gallery corners, up to 100 m away from the equipment, in the lowest radiation and magnetics field condition of the Tokamak building.

Residual Gas Analyzers (RGA) and capacitive gauges, also foreseen for the cryopump controls, do not permit such implementation since local signal conditioning is required for their correct operation. Partially delocalized and shielded electronics in neighboring shaded locations is therefore of current consideration. Residual gas analyzers will be implemented with passive transducer heads and pre-conditioning electronics delocalized up to 15 m away just outside the port cells (RGA). Commercially available capacitive gauge do not allow such distances between the sensing elements and the conditioning bridge, so provision has been made for side implementation of field end electronics protected behind the bioshield and featuring local magnetic shielding. This enables the conditioning electronics to be located only a few meters away from the transducer head.

3.2. Cryopumps temperature sensors

Specific TVO (Carbon Ceramic Sensor) and Cernox® temperature sensors providing measurements from 4 K to 500 K under 0.4 T and above 1 MGy radiation level have been preselected and thermal cycling tests have been performed at CEA/SBT[1] to assess their behavior in high temperature operation and the effect of thermal cycling on their accuracy. 33 thermal cycles have been recorded between these extreme temperatures, and all 10 tested sensors survived the cycling and even experienced very limited shifts, as detailed in Table 1 (all measuring chain errors included). Both

[1] Commissariat a l'Energie Atomique de Grenoble – Service des basses Températures.