INTEGRATION OF DIAGNOSTICS INTO THE ITER MACHINE

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Abstract

This paper defines and discusses the integration of diagnostics systems into the ITER machine. For each machine region, the key constraints and solutions adopted are discussed, and illustrated with selected examples.

1. THE INTEGRATION PROCESS

In order to meet the ITER programmatic and operational goals it is necessary to measure a wide range of plasma parameters as well as the condition of the first wall and divertor target plates [1]. Thus there is a need for an extensive collection of individual measurement systems (diagnostics) which together form the ITER diagnostic system. Integration of this system into the ITER machine is the iterative process of allocating space for each diagnostic following a set of priorities, and resolving all the interface issues between the diagnostic and other machine systems (including other diagnostics) or operations (including maintenance). Priorities for the diagnostics largely follow the categorisation of measurements [2]: these are 1a) those necessary for machine protection and basic control; 1b) advanced control; and 2) physics understanding. Interface issues [3] dominate the integration process, making it natural to discuss integration by location [4].

There are four main areas where diagnostic components are installed:

a) *equatorial port:* LIDAR Thomson scattering, wide angle viewing in visible and IR, radial neutron camera, bolometers, polarimeter, tangential interferometer/polarimeter, ECE, edge reflectometers, X-ray crystal spectroscopy, vacuum-UV spectroscopy, active spectroscopy (MSE and CXRS), neutral particle analyser;
b) *back plate and vacuum vessel (VV)*: Magnetic pick up coils and flux loops, bolometers, soft x-ray diodes, position reflectometers, high-field side profile reflectometers;
c) *vertical port*: bolometers, impurity monitors, edge Thomson Scattering, neutron activation, vertical neutron camera, wide angle viewing in visible and IR, In Vessel Inspection (IVI);
d) *divertor cassette*: Impurity spectroscopy, target IR viewing, reflectometry, Langmuir probes, pressure gauges, magnetic pick up coils, bolometers.

The integration of diagnostics must be consistent with the number of ports allocated, the design of the port plugs and in-vessel machine components, nuclear shielding requirements, tritium containment and vacuum requirements, as well as maintainability with remote handling equipment both in the vacuum vessel and in the Hot Cell. The main shielding requirements are met by labyrinthine access penetrations, while materials survivability is met by the choice of materials for the exposed front end components [5]. Thus the above requirements which arise in an ITER like machine serve as the primary design drivers, posing a new design challenge.

2. THE RESULTS

Equatorial Ports. The equatorial ports are the preferred location for diagnostics. Three regular ports and one port having limited access (adjacent to the NBI) are fully used. Two further ports allocated to Remote Maintenance can include diagnostics which can be quickly removed. All diagnostic equipment inside the VV ports is mounted in an integrated shield plug incorporating a first wall/blanket part, a VV port plug for shielding and a VV closure plate (Fig. 1). In order to simplify and to standardise the maintenance of these VV plugs, modular sub-assemblies are replaceable without completely dismantling the plug (Fig. 1). Services and cooling connections, mechanical attachments for larger plug subassemblies as well as positioning and alignment of these subassemblies use a standardised, limited, set of Hot Cell tooling. The space between VV and cryostat is bridged by an interspace diagnostic block (incorporating the cryostat closure plate and all equipment needed between VV and cryostat closure plate). Thus only two large pre-tested assemblies have to be installed / removed (remotely), while most of the repair is performed off-line in the Hot Cell. An exception are windows on the primary closure plate which can be replaced in-situ.

Different factors have to be taken into account in optimising the distribution of diagnostics inside these plugs and among the available ports: for example, large aperture systems such as the LIDAR optics (Fig. 1) or the neutron camera aperture have to be placed at port centres and tangential viewing systems at the sides of ports. Systems which need to view one of the Heating Neutral Beams and the Diagnostic Neutral Beam, as well as ports incorporating wide angle viewing systems (maximising plasma or wall coverage), need to use specific ports. Systems requiring vacuum extensions have to use the port adjacent to the NBI in order to utilise the existing pressure vault.

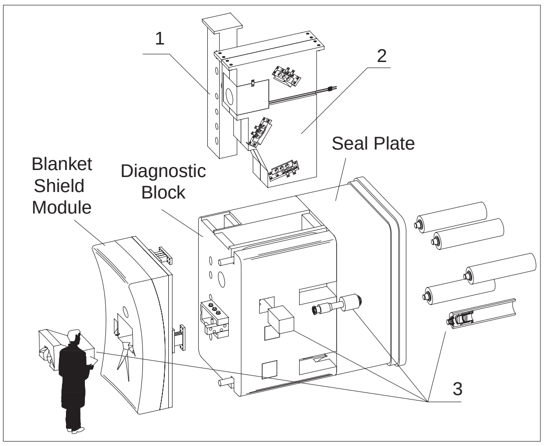

FIG. 1. Port No. 16 showing (1) the mirror rack for H_a (2) the mirror rack for LIDAR and (3) the removable parts of the wide angle viewing system.

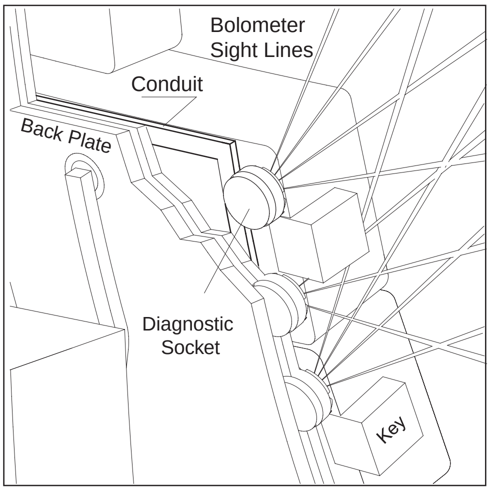

FIG. 2. The Diagnostic Socket on the back plate. Bolometer cameras view through the space between Blanket module gaps

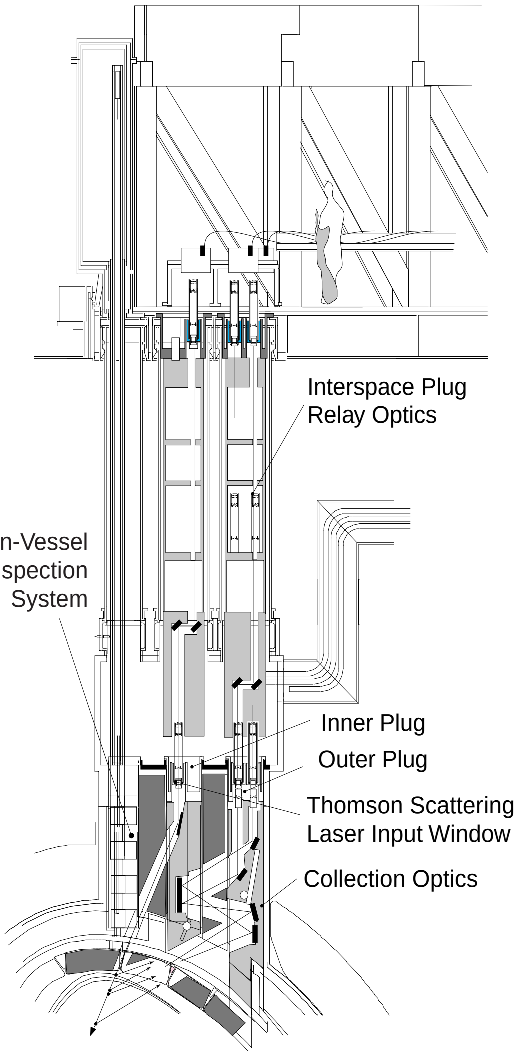

FIG. 3. The vertical port with the edge Thomson scattering system. Also indicated is the off line inspection system. Access for installation and maintenance is from the top.

For each port, it is necessary to ensure that the overall neutron shielding is not worse than the unbroken shield of the blanket + VV structure. In addition, for each aperture a special blanket/shield has to be designed so as to tolerate the same conditions as any other part of the first wall. These requirements can have a large influence on specific diagnostic designs e.g., favouring small apertures, as well as in the layout of diagnostics within the port. A particularly difficult area in this respect is the port incorporating the VUV, X-ray crystal spectrometry and NPA systems which need a primary vacuum extension into the pit (NBI vault) [6]. However in this case individually minimising the aperture for each X-ray/VUV or NPA channel yielded an acceptable neutron streaming allowing hands-on maintenance in the NBI vault. Figure 1, which shows the exploded view of the port plug, blanket section and vacuum closure plate of the LIDAR port #16 [7] gives an example of the above outlined principles.

Backplate and Vacuum Vessel. The majority of the in vessel diagnostic systems are mounted on the plasma side of the back plate (some are on the VV wall). Most systems mounted on the back plate are essential for tokamak operation (e.g., magnetic diagnostics [8]) and so require redundancy. In addition, they are in a difficult environment, and must tolerate the possible removal of a Torus sector and so require reparability. The primary integration concern for these systems is to have minimum impact on the blanket, which is already constrained because of high thermal, radiation and electromechanical loads. Additional constraints comes from the back plate, which is highly stressed in disruptions and will not tolerate long grooves for conduits, and from the VV, which is a pressure vessel and must not be disturbed. Thus, these diagnostics view the plasma through the gap between blanket modules (Fig. 2) which are sometimes slightly enlarged. With the exception of the various magnetic flux loops and reflectometer heads [9], all sensors are mounted in small replaceable conduction cooled diagnostic sockets embedded in the back plate (Fig. 2). Wiring and other connections to the front ends of these diagnostics are grouped to a single conduit per sector. Space for this conduit is provided in the back of the blanket modules.

Vertical Ports. Ten vertical ports are allocated to diagnostics. They are shared with the off-line in-vessel inspection system and the retractable glow discharge cleaning electrodes. Due to the large distance between the VV top port and the cryostat lid (~ 7 m) and substantial movements between these two large machine components, this interspace is bridged by three articulated vertical pipes (one with 600 mm diameter and two with 860 mm diameter) located along a radial line on top of the vertical VV port (Fig. 3). The smaller pipe is occupied by the IVI system whereas the other pipes provide access to two integrated diagnostic plugs mounted in the VV top port. Again, two interspace blocks are provided to keep diagnostic equipment inside these pipes modular and permit the simplest possible extraction. This is illustrated in Fig. 3 where the port with the edge Thomson scattering system is shown [10]. The two diagnostic plugs in each VV port (each 700 mm diameter and ~ 4 m long) incorporate various diagnostic systems and in some cases the glow discharge electrodes. They are inserted into a fixed shield which is part of the VV top port. In contrast to the equatorial ports, they do not include a blanket component. The penetration through the blanket is also standardised and is a slot 150 mm wide and 2.4 m long. The remote maintenance employs a special vertical cask whose dimensions have been minimised by dividing the vertical length of the interspace blocks and the diagnostic blocks into components ~ 4.5 m long. The cask can be taken to the Hot Cell where the interspace blocks are repaired hands-on while the diagnostic blocks require remote maintenance, in most cases limited to the exchange of relatively big sub-components.

Divertor. In the divertor, diagnostic components are located inside the four remote handling ports and on the divertor cassettes in front of these ports. At each of the four locations there are two instrumented cassettes (Langmuir probes, bolometers, pressure gauges, etc.) on either side of a central cassette. The latter is modified to incorporate optical and microwave diagnostics (Fig. 4).

In order to avoid delays in the maintenance of the divertor, remote maintenance inside the machine is performed for the diagnostic cassettes in the same way as for standard cassettes. In the space between the VV closure plate and the divertor cassettes a diagnostic block is installed which functions as a carrier for wave guides and optical relay equipment, and can be removed in a simple operation. Similarly, in the pit, equipment is designed for easy removal. In order to minimise activation at the cryostat, special shielding is added around windows. Integrated assemblies are mounted on the diagnostic cassettes (e.g., side plates incorporating various sensors) to allow relatively simple replacement of diagnostic components inside the Hot Cell. These inserts make efficient use of the limited non-structural space available within the cassette body. In order to minimise the impact on plasma facing components, diagnostics view the plasma through narrow (25-35 mm) slits between target plates, or though the central dome. Some of these features are illustrated in Fig. 4 for the impurity monitoring system [11].

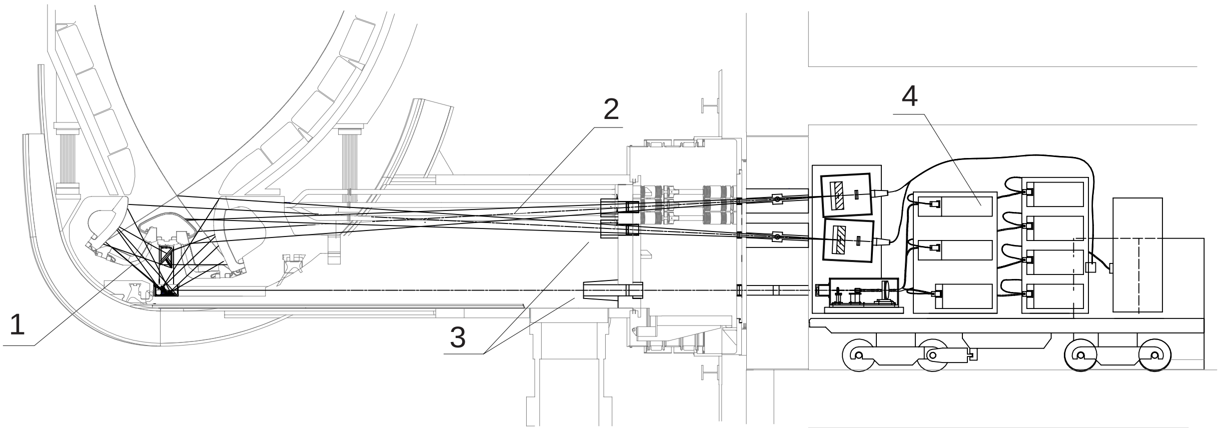

FIG. 4. The impurity monitoring system for the divertor, showing (1) a mirror system under the dome for the observation of both divertor legs (2) a UV system viewing through the gap between the cassettes (3) radiation shielding around the primary vacuum windows and (4) instrumentation in the access cell designed to roll out of the way of remote handling equipment.

3. CONCLUSIONS

Through a combination of specially designed machine components, selection of measurement methods and materials for diagnostic components, as well as the use of new measurement techniques it has been possible to integrate most of the required diagnostics into ITER. In particular, all the diagnostic systems which provide measurements in category 1a have been accommodated and most of those which provide measurements in categories 1b and 2. Thus it has been demonstrated that a diagnostic set of similar measurement capability or even better than in present day machines can be realised in a reactor class machine like ITER.

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