

In vessel electrical integration in ITER—Requirements & solutions

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ABSTRACT

The ITER in-vessel electrical integration has been divided between several engineering activities to complete the distribution of more than 4000 cables around the inner wall of the vacuum vessel and divertor, using the upper and lower ports to exit from the vessel. Having met difficult requirements, this integration enables the measurements of key parameters of the burning ITER plasma. Most of the cables are mineral insulated (MI) cables with different diameter and type (twisted pair, quad core, triaxial, coaxial), with complex routing from the sensor to vacuum feedthrough across an in-vessel loom using a connection box located in a marshaling area at the ports. These cables have the function to connect the diagnostic sensors, located into the machine, to the data acquisition hardware in the diagnostic hall for plasma diagnostics and blanket and vessel monitoring Martinez et al. [3]. The in-vessel looms and the cables have to achieve adequate thermal contact to the vessel for cooling, and adequate neutronic protection for suitable performance of their measurement functions. The integration constraints for routing the in-vessel looms and cable tails behind blankets, and also the assembly constraints for these components will be described in this manuscript.

1. Introduction

This paper will describe the electrical configuration for the in-vessel sensors of the ITER tokamak. In this section, components will be defined to understand the complex environment for the electrical integration. The second section will be used to introduce the loom designs. Section III will describe the cabling and the structural loom design and Section IV will describe the routing of the tail cables to exit from the ports. The feedthroughs are described in Section V, and Section VI will discuss the assembly sequences for cables into the loom.

The ITER vacuum vessel (VV) is divided into 9 similar sectors where sensors will be located. In addition to the magnetic sensors for plasma diagnostics, sensors for monitoring the vessel and the blankets are also present. [1]. As shown in Fig. 1, the VV is a double wall torus structure made of stainless steel (316L(N)-IG, ITER grade) [2]. The blanket modules will be supported directly by the VV, and the blanket cooling manifolds will be mounted on the plasma-side surface of the VV inner wall. The inner and outer shells are both 60 mm plate and the stiffening ribs between the shells are 40 mm plate.

As shown in Fig. 2, the VV consists of the main vessel, the port structures and the VV supporting system. The 9 toroidal sectors are

joined by field welding using splice plates at the central vertical plane of alternate ports (of the odd numbers). All sectors have approximately the same design of the ports, including gravity supports. Three sectors have different equatorial ports, and are termed irregular sectors. In conclusion, there are 9 lower ports and 18 upper ports, each with different electrical services (See Fig. 3).

The divertor consists of 54 modules fastened to 2 concentric toroidal rails welded to the VV. The other major components are in-vessel coils (IVCs) for stability control. These include three sets of Edge Localized Mode (ELM) suppression coils (upper, mid-plane and lower) per sector, and upper and a lower toroidally continuous vertical stability (VS) coils, located respectively above the upper and the lower ports. They are placed behind the blanket and under the blanket manifolds.

The blanket manifolds comprise a system of individual SS316L seamless pipes routed through the VV upper port into the VV main chamber where they feed the individual blanket modules. Adapted to the VV design, the manifold assembly consists of an inlet and outlet bundle of pipes for the inboard and for the outboard blankets. The inboard bundles are routed over an upper VS coil and then directly fixed onto the VV inner wall, whereas the outboard bundles are routed over a set of ELM coils and a lower VS coil. The outboard manifolds straddle

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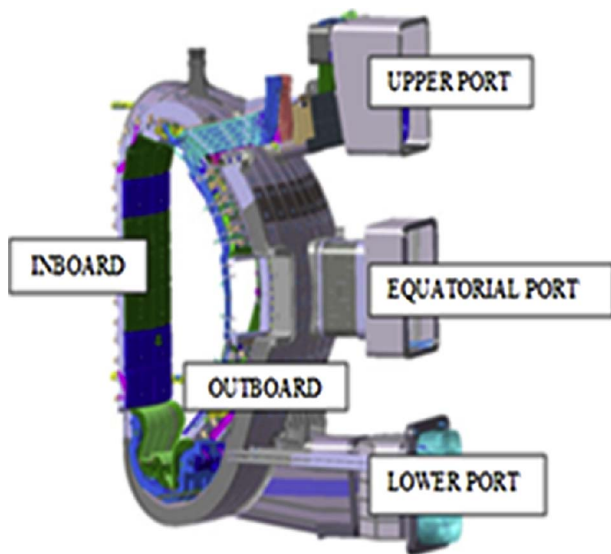


Fig. 1. ITER Vacuum vessel overall structure.

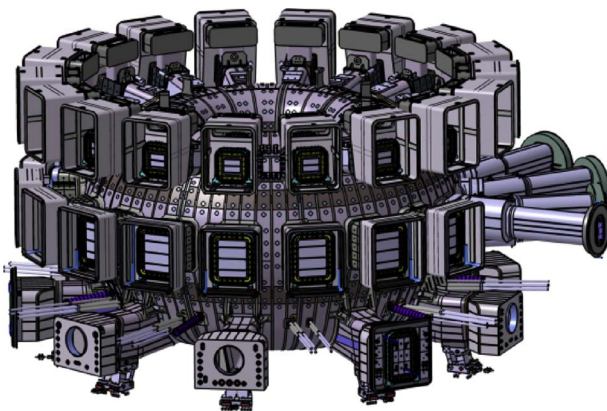


Fig. 2. Fully assembled ITER vacuum vessel.

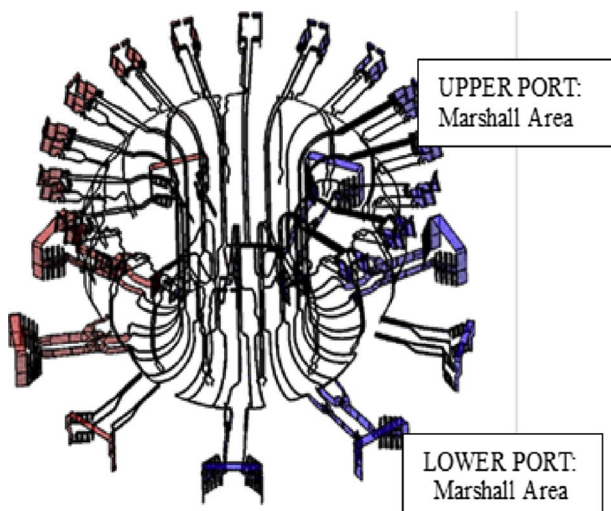


Fig. 3. In-vessel looms.

the IVCs and are fixed onto the manifold VV rails independently, so there are no loads communicated between the two systems.

In addition to the IVCs and blanket manifold systems, their VV rails and intermodular keys; there are 440 blanket modules with associated first walls panels. Other hardware includes fueling and gas injection

lines.

Once the main components listed above are positioned on the wall of the VV, the in-vessel diagnostics [3,4,6] and vacuum vessel and blanket sensors must be integrated in the available space with appropriate geometrical requirements and clearances. The corresponding cable looms must then be routed along the VV shell to exit points at the ports. The list of clients for electrical services has been defined in [8], and is listed in Table 2.

The primary function of the in-vessel wiring looms is to provide infrastructure to bring out electrical signals from sensors on the inside of the vacuum vessel. This must be done in a way that has no impact on the operation of ITER and its primary project goals. The cabling infrastructure must therefore occupy as little space as possible, in order to maximize the volume required for the plasma and other components. The materials used must survive the environment in ITER and not degrade the quality of the vacuum inside the vacuum vessel. Any material used must have acceptable outgassing rates including during periodic baking cycles (where the VV temperature is increased to 200C). In addition, any attachment of cable supports to the VV must have no impact on its pressure vessel status. A summary of the main requirements for in-vessel cabling is given in Table 1, and a full listing can be found in Ref. [12].

Plasma diagnostic sensors are arrayed at a variety of positions according to their function (see Ref. [5]).

2. In vessel loom configuration

For most of the distance between the sensor and the feedthrough, cables are routed in supported groups called looms, shown in Fig. 5. This loom skeleton is around the entire machine, sandwiched between the VV inner surface and the blanket modules. There are typically 12 cable looms in each sector, shared between inboard sensors (4 exiting at lower ports and 4 at upper ports) and outboard sensors (4 exiting through upper ports).

Since there are 18 upper ports and 9 lower ports, there are twice the numbers of looms arriving at each of the lower ports. This is illustrated in Fig. 5. Note that the outer looms are routed to the upper ports, along with the inner looms serving sensors from blanket module 4 and upwards. Inboard looms below this level are routed to the lower ports. In addition, in the lower ports, cabling from divertor looms and main vessel diagnostic looms combine in the marshaling area, as shown in Fig. 6. This area is located midway out in each lower port extension.

The loom size is constrained by the need for the looms to be integrated with other components. For example, the outboard looms cross under the IVCs, limiting the capacity of these looms to 24 cables, compared to the 36 cable limit for the inboard looms. In some sectors, the reflectometry waveguides limit the space available for looms.

The pie chart in Fig. 4 shows the number of cables per sector and Table 2 lists the diagnostic cable clients. Ref [8] has a total list of in-vessel cabling, and includes the type of cables, feedthrough locations, cabling population, and electrical information.

The marshaling area shown in Fig. 6 was positioned to facilitate the connection of the in-vessel sensor cables to the feedthrough cables. The spatial geometry was driven by the presence of the nearby structures, including the port plugs, the diagnostic racks, the cooling manifolds, and the IVC coil feeders (for the top ports). Another important constraint was the bending radius of the MI cables. The sensor cables are installed into the VV sectors before the sectors are assembled. Since the MI cables are cut and terminated before the VV assembly, the route of individual cables must be corrected to compensate for expected inaccuracies involved in VV manufacturing and assembly. This compensation takes place in the marshaling area. Numerous routing strategies were proposed and checked by all stakeholders to minimize risk in assembly, operation, and maintenance phases.

Due to space limitations in the feedthrough area, a further constraint is the feedthrough capacity, currently fixed at a maximum of 66

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