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Manufacturing, assembly and tests of SPIDER Vacuum Vessel to develop and test a prototype of ITER neutral beam ion source

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HIGHLIGHTS

- The SPIDER experiment aims to qualify and optimize the ion source for ITER injectors.
- The large SPIDER Vacuum Vessel was built and it is under testing at the supplier.
- The main working and assembly steps for production are presented in the paper.

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ABSTRACT

The SPIDER experiment (Source for the Production of Ions of Deuterium Extracted from an RF plasma) aims to qualify and optimize the full size prototype of the negative ion source foreseen for MITICA (full size ITER injector prototype) and the ITER Heating and Current Drive Injectors. Both SPIDER and MITICA experiments are presently under construction at Consorzio RFX in Padova (I), with the financial support from IO (ITER Organization), Fusion for Energy, Italian research institutions and contributions from Japan and India Domestic Agencies. The vacuum vessel hosting the SPIDER in-vessel components (Beam Source and calorimeters) has been manufactured, assembled and tested during the last two years 2013–2014.

The cylindrical vessel, about 6 m long and 4 m in diameter, is composed of two cylindrical modules and two torispherical lids at the ends. All the parts are made by AISI 304 L stainless steel.

The possibility of opening/closing the vessel for monitoring, maintenance or modifications of internal components is guaranteed by bolted junctions and suitable movable support structures running on rails fixed to the building floor. A large number of ports, about one hundred, are present on the vessel walls for diagnostic and service purposes.

The main working steps for construction and specific technological issues encountered and solved for production are presented in the paper. Assembly sequences and tests on site are furthermore described in detail, highlighting all the criteria and requirements for correct positioning and testing of performances.

1. Introduction

PRIMA (Padova Research Injector Megavolt Accelerated) is the name of the ITER Neutral Beam Test Facility currently under construction in Padova (Italy) [1]. PRIMA hosts two test-beds named respectively SPIDER (Source for Production of Ion of Deuterium Extracted from RF Plasma) [2], aiming to developing and optimizing the ion source, and MITICA (Megavolt ITER Injector Concept Advanced) [3], which is the full size prototype of the ITER Heating and Current Drive Injector. Both test-beds accelerate negative ions with a maximum energy of 870/1000 keV for MITICA and 100 keV for SPIDER, and a maximum beam current of 49/40 A in deuterium/hydrogen. The SPIDER Vacuum Vessel has been manufactured and is presently under pre-assembly and factory testing at the supplier's premises.

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2. Main characteristics of SPIDER Vacuum Vessel

The SPIDER Vacuum Vessel is an AISI 304 L cylindrical vessel, about 6 m long and 4 m in diameter, composed of two cylindrical modules and two torispherical lids at the ends (see Fig. 1).

The modularity of the vessel, removable closures at the ends and the possibility of running on rails of modules and lids were conceived to guarantee easy and fast access to the components during maintenance and shutdown periods.

A large number of ports are located on modules and lids to allow access for diagnostics purposes and connection to service lines (cooling, vacuum, signals for monitoring and feedback control of the experiment).

A full description of the vessel, from requirements to design choices, structural analyses and verifications are reported in [4].

3. Manufacturing of the vacuum vessel

In 2013 and 2014 the manufacturing of the vacuum vessel was performed by Zanon S.p.A. (Italy) under F4E contract, as European contribution to ITER.

During a first phase a thorough design review was performed to optimize it for manufacturing reasons. The main change regarded the increase of the size for connection flanges of modules and lids (see Fig. 2a). This change was judged advisable to guarantee a sufficient stiffness of modules and lids during machining and handling of components, avoiding the need of specific stiffening tools and minimizing the risks of deformations during welding and machining phases. With the same aim the T shape stiffening ribs in correspondence of the middle sections of modules have been substituted with massive ribs. This change also allowed a manufacturing simplification (see Fig. 2b).

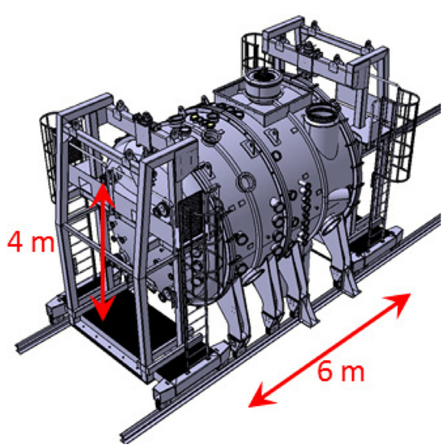

Fig. 1. Overall view of SPIDER Vacuum Vessel.

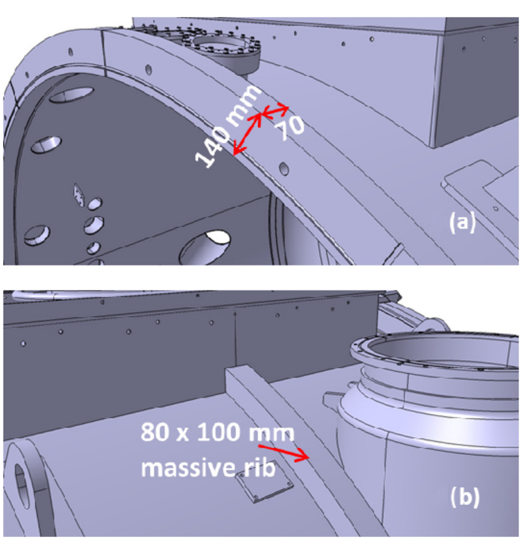

Fig. 2. Details of main design changes according to manufacturing requirements.

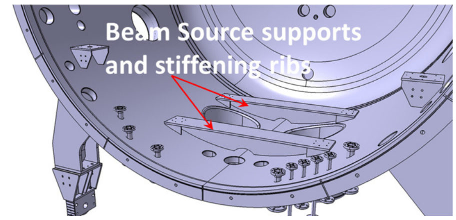

Fig. 3. Details of the Beam Source supports and internal stiffening ribs.

Further improvement of vessel stiffness was achieved by modifying the Beam Source supports: two continuous supporting “T” ribs welded to the wall were added, as shown in Fig. 3. The new support design gives a proper increase of local stiffness of the vessel close to the most critical interface points.

Other minor changes regarded details of pipes and flanges welds, optimized for an easier manufacturing and better access for X-rays testing reasons.

The system for vessel support, wheels and rails has been developed in detail as shown in Fig. 4. Commercial products by Demag S.p.A. were adopted, with integral solutions for rails, wheels, shafts and electrical motors. Motorized running on rails was applied to the two lids only, since each of the two modules with free wheels can be moved together with the correspondent lid. These changes allow smooth and well controlled running of modules and lids on the rails keeping the free space required under the vessel for maintenance and diagnostics installation.

The main phases of the vessel manufacturing are shown in the following figures. The 15 mm thick stainless steel (SS) sheets of modules have been cut, bending rolled and welded to form the cylindrical shell stiffened by suitable cross-bracings to keep the correct shape during manufacturing. In parallel the 25 mm thick sheets have been cold formed to get the torispherical shape of the two lids, having nominal minimum thickness of 20 mm after cold forming (see Fig. 5).

Then the forged SS flanges and the stiffening ribs have been prepared and welded to the modules and lids. Apertures of ports were machined on the walls and other features as plates for external fixings were welded (see Fig. 6).

The welds were carried out with SAW or TIG processes, optimizing the welding process and with proper stiffening tools to minimize distortions during welding and machining.

The finishing of flanges contact surfaces and grooves for Viton® o-rings was performed on precise CNC milling machine and vertical turret lathe.

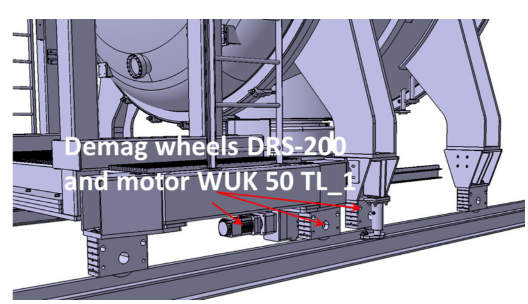

Fig. 4. Details of supports, wheels and rails.

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