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Manufacturing of the JT-60SA cryostat vessel body cylindrical section

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HIGHLIGHTS

- Design features.
- Manufacturing procedure.
- Assembly/welding of sectors on dedicated welding frames.
- Machining phases.
- Dimensional inspection of individual sectors.
- Assembly at factory and final dimensional inspection.
- Reference marks, cleaning and packing.

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ABSTRACT

The JT-60SA cryostat is a large vacuum vessel made up of 304 stainless steel which encloses the tokamak providing the vacuum environment to reduce thermal loads on the components at cryogenic temperature. It must withstand the external atmospheric pressure during normal operation and the internal overpressure in case of an accident. Due to functional purposes, the cryostat has been divided in three large assemblies: the Cryostat Base (CB), the Cryostat Vessel Body Cylindrical Section (CVBCS) and the Top Lid. The CB was manufactured in Spain and assembled in-situ in 2013, while the CVBC is currently under manufacturing also by a Spanish company and it is expected to be delivered in Naka next year 2017. This paper gives an overview of the manufacturing process and present status of the CVBCS. The manufacturing includes the assembly and testing at the manufacturer workshop as well as the packaging of the component. The reference code being used for the manufacturing is ASME 2007 Section VIII Div.2.

1. Introduction

The JT-60SA tokamak, to be assembled and operated at the QST laboratories in Naka (Japan), is a combined project of QST's Japan national program and JA-EU Satellite Tokamak Program [1,2]. The European contribution to the JT-60SA is procured in kind by France, Italy, Spain, Germany and Belgium. Within this framework, Ciemat is in charge of the design and manufacturing of the JT-60SA cryostat (Fig. 1).

The main parameters and features of the cryostat are summarised in Table 1. Due to the transportation constrains posed by the port of entry and the QST site, the cryostat assemblies have to be suitably segmented. The CVBCS comprises twelve sectors and the CB seven pieces.

2. CVBCS design

The design has been validated by Finite Element Analyses [3] (buckling, elastic and elastic-plastic and load limit analyses) according to ASME 2007, Section VIII, Div. 2. The CVBCS is built by cylindrical sections connected by truncated-conical elements. It consists of a single-shell vessel (34 mm thickness for shielding pur-

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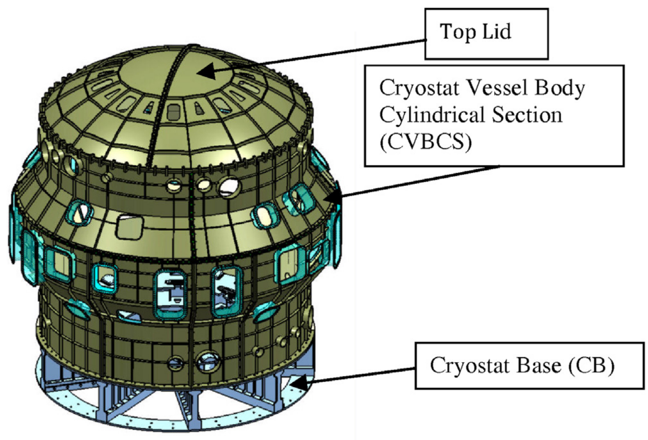

Fig. 1. JT-60SA Cryostat.

Table 1
Cryostat main parameters and features.

JT-60SA Cryostat	
Structural material	SS304 (Co < 0.05 wt%)
Operational pressure	Vacuum, 10^{-3} Pa
Potential internal overpressure	0.12 MPa absolute
Total surface/volume	$1368\ m^2/1410\ m^3$
Leak rate against air	$10^{-4}\ Pa\ m^3/s$
Cryostat dimension	Ø 13.47 m × 15.85 m
CB section	Ø 11.95 m × 2.84 m
Typical plate thickness	20/34/49/100 mm
Cryostat weight	~468 t
CVBCS weight	~175 t (top lid excluded)
Vacuum sealing concept	Inside/outside fillet welding
Design temperature	293 K

poses) externally reinforced with 20 mm thick ribs. Bolted flanges connect the different sectors of the vessel body, sealed by thin non-structural welds performed from inside/outside of the cryostat. The sectors are very flexible due to their open geometry, relatively thin wall and a large number of openings/ports of different dimensions. Nevertheless the related tolerance requirements are very tight: ±4 mm in height, ±4 mm in radius on main flanges and ±0.25 mm flatness on machined surfaces. The cryostat shell has a tolerance of ±10 mm in radius and the centre of the ports must maintain its absolute position within a tolerance of ±8 mm.

The CVBCS supports the weight of all the ports and port plugs and also loads from the operation of the experiment in normal/abnormal conditions (such us vacuum pressure/overpressure, electromagnetic loads) or external events such as seismic loads. The CVBCS will be assembled onto a strong structure: the CB [4] that bears the loads of the entire machine and transfers gravity and seismic loads to the foundations of the experiment in the Torus Hall. The upper side of the CVBCS will be closed by a top lid which will be provided by QST.

The CVBCS is subdivided in two main assemblies, the bottom part (consisting of 8 sectors) and the top part (consisting of 4 sectors), see Fig. 2. The CVBCS will be pre-assembled at the factory, adjusted and dimensionally inspected before shipment to Japan where it will be finally assembled on-site. All joints between the CVBCS sectors will include some pins to define their position after assembly. The cryostat has many openings, some as large as 2322 mm × 1152 mm, where ports will be welded to accommodate the ducts to the vacuum vessel (VV), toroidal magnet service components (cryogenic terminal boxes, valve boxes), manholes with lids to get inside, and where assembly of sensor boxes, in-cryostat feeders, etc. will be fitted. Large bellows are used in between the cryostat and the VV to accommodate differential thermal expansion and fabrication tolerances of the structures.

The base material for the fabrication of the CVBCS, S30400 (UNS reference code) with some special requirements (Co < 0.05 wt%, magnetic permeability < mu > rel ≤ 1.1 on surface and surface finish Ra ≤ 12.5 < mu >m), was manufactured by Outokumpu (Sweden) and supplied to QST. The thickness of the plates ranges from 20 to 100 mm. The manufacturer of the CVBCS has verified and accepted the material in terms of quantity, dimensions and thicknesses. A dummy piece of the CB is provided by the manufacturer for use in the final pre-assembly at the factory. An extra dummy piece is also necessary for the pre-assembly of the upper sectors. The filler material for welding is AISI 308LSi.

3. Manufacturing

The manufacturing contract has been awarded to the Spanish company Asturfeito S.A. in November 2013. The manufacture includes the detail design (manufacturing drawings, weld plans, etc.) and the fabrication of the CVBCS. The fabrication plan comprises the following steps: qualification of specified welding and non-destructive examination (NDE) processes, design and manufacturing of welding frames, jigs and fixtures, cut of the plates by water jet machine, beveling for welds preparation, forming parts, welding phases, NDE tests and stress relieve cycles, machining phases, assembly at factory, intermediate and final dimensional survey by laser tracker, cleaning and packaging. Packaging of CVBCS shall be suitable for shipping the component to a port of entry in Japan.

Manufacturing started after the approval of technical documents that include manufacturing drawings and procedures, and qualification reports (welding procedure specification WPS, procedure qualification record PQR, ultrasonic tests, etc.). The QA includes documentation schedule, manufacturing schedule, quality plan, risk management plan, progress reports, changes and non-conformity records, list of subcontractor and minutes of the meetings.

3.1. Cutting, bevelling and forming of parts

Cutting of the plates have been performed in a high pressure water jet machine, to avoid heat affected zones and taking advantage of the good accuracy and quality finishing of the cut surfaces. After the cutting operation the edges of the different plates have been bevelled (V/K bevels type) in different milling machines. Forming of the different parts has been properly done with two types of machines: roll bending machine (cylindrical parts) and press brake machine (conical parts). These formed parts do not contain port holes and openings to prevent distortions during forming and welding.

3.2. Qualification of the welding process

Prior to start production the welding process as well as the welders involved in the fabrication were qualified according to ASME Section IX. GMAW semi-automatic has been used as welding process, in accordance to Section IX, PART QW of ASME Code (2007) and the standards applicable gathered within this code.

3.3. Assembly/welding activities

Dedicated welding frames were designed and manufactured in order to facilitate the assembly and welding activities. Three types of frames have been made: two types for the upper and lower sectors respectively with the sector facing up (see Fig. 3) and two units of the third type with the sector facing down (see Fig. 4) in order to

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