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Features and analyses of W7-X cryostat system FE model

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ABSTRACT

The Wendelstein 7-X stellarator is presently under construction at the Max-Planck-Institute for Plasma Physics in Greifswald with the goal to verify that a stellarator magnetic confinement concept is a viable option for a fusion power plant.

The main components of the W7-X cryostat system are the plasma vessel (PV), outer vessel (OV), ports, thermal insulation, vessel supports and the machine base (MB). The main task of the cryostat system is to provide an insulating vacuum for the cryogenic magnet system while allowing external access to the PV through ports for diagnostic, supply and heating systems.

The cryostat is subjected to different types of loads during assembly, maintenance and operation. This ranges from basic weight loads from all installed components to mechanical, vacuum and thermal loads. To predict the behavior of the cryostat in terms of deformations, stresses and support load distribution a finite element (FE) global model has been created called the Global Model of the Cryostat System (GMCS).

A complete refurbishment of the GM CS has been done in the last 2 years to prepare the model for future applications. This involved a complete mesh update of the model, an improvement of many model features, an update of the applied operational loads and boundary conditions as well as the creation of automatic post processing procedures.

Currently the GMCS is used to support several significant assembly and commissioning steps of W7-X that involve the cryostat system, e.g. the removal of temporary supports beneath the MB, transfer of the PV from temporary to the final supports and evacuation of the cryostat. In the upcoming months the model will be used for further support of the commissioning of W7-X which includes the first evacuation of the PV.

1. Introduction

The WENDELSTEIN 7-X (W7-X) stellarator experiment is currently under construction at the Max-Planck-Institute for Plasma Physics in Greifswald. Design, manufacturing and assembly of the main structural components have finished and focus is now lying on commissioning of the basic device [1] and manufacturing and assembly of diagnostics and peripheral systems.

The W7-X cryostat mainly consists of the Outer Vessel (OV), the Plasma Vessel (PV), 254 ports with bellows that connect the vessels, and the thermal insulation (Fig. 1). The OV, PV and ports enclose the volume of the cryostat. The cryostat provides an insulating vacuum for the W7-X cryogenic magnet system (MS) which is enclosed by the cryostat while allowing external access to the PV through ports for diagnostic, supply and heating systems. The cryostat is positioned on the machine base (MB) through PV- and OV-supports. The PV-supports consist of horizontal and vertical supports. These supports can also be used to adjust the position of the PV relative to the OV.

The cryostat and the MS have separate and independent supports. The MB forms the only interface between the MS and the cryostat. As the only interaction is basically dead weight deformation of the MB, the structural behavior of both MS and cryostat can be assessed independently.

Both for the cryostat and the MS finite element (FE) global models have been created to be able to analyze the global behavior of both systems with respect to displacement, stresses and load distribution ([2,3]).

In 2014 the W7-X has started commissioning of the basic machine in preparation of achieving first plasma in mid-2015 [1]. This paper focuses on the verification of the global model of the cryostat system (GMCS) using measurements performed during the first commissioning steps.

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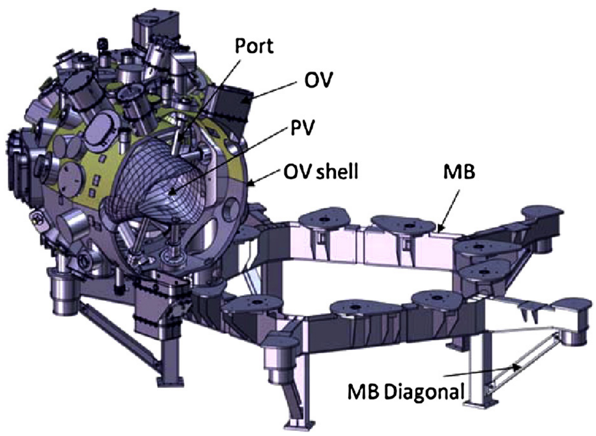

Fig. 1. W7-X cryostat: 1 of 5 modules incl. MB.

2. FE analyses with GMCS

2.1. Model revision

To prepare the GMCS for the commissioning phase the model has been revised compared to the status as presented in [3]. The revision included the following changes:

- Introduction of port reduction for PV and OV (from 299 to 254 ports).
- Updated geometries and improved mesh and for vessels, ports and PV supports incl. updated shell element type.
- Introduction of contact and compression-only elements at PV horizontal and vertical supports [4].
- Port bellows and the torus hall (TH) floor simulation and using super elements.
- Update of load cases incl. update of thermal load distribution.
- Creation of a large set of post processing macros for extracting the most relevant structural output from the GMCS FE results.

2.2. GMCS load cases

During operation, the cryostat system of the W7-X stellarator is subjected to different types of loads. The loads cover weight, thermal, electro-magnetic and vacuum loads. In addition a set of abnormal cases is taken into account to determine the impact of certain fault scenarios like He- or water-pipe leakage and subsequent over-pressure in the vessels or eddy current loads induced by a fast shutdown of the main magnet system. Table 2 shows a selection of typical load cases (total 21) as covered by the GMCS. For all load cases the weight of the MS is included. In addition weight and active loads for KIP, diagnostics and peripheral systems is included in the GMCS.

3. GMCS verification during W7-X commissioning

3.1. Metrology

For verification of the GMCS results geometrical measurements [5] were carried out during load changes forced by the removal of temporary supports and evacuation as well as venting of cryostat.

The principal approach of these measurements accompanying the load changes was:

- Installation of targets at positions discussed between metrology and engineering group. Usually RFIs (reflector for fixed installation) are used for targets.
- Orientation of the measurement system to the global W7-X co-ordinate system which is represented by 128 reference points fixed on the TH walls.
- Initial reference measurement of target co-ordinates before start of load change.
- Frequent measurements of target position during load transients incl. quasi-real time data transfer to the responsible engineers.

The most appropriated measurement tools for these tasks are Laser-Trackers (LT). The metrology group at IPP owns LT from Leica with a guaranteed measurement uncertainty of $\pm 10\,\mu m/m \pm 25\,\mu m$ for a 3D co-ordinate. For W7-X, i.e. inside the TH ($32 \times 30 \times 15\,m^3$) including effects like air condition and daily assembly work, the measurement uncertainty can be estimated by 0.3 mm for the global position of a target and 0.1 mm for repetition measurements. To achieve these accuracies the atmospheric conditions within the TH play a significant role. It was required to find a compromise between keeping stable temperature conditions through air conditioning and minimizing air flow in the TH. The LT are sensitive to temperature gradients as the layers of different air densities influence the laser path. The turbulences due to air flow when the air conditioning is on increases the noise on the measured values. The compromise chosen in many cases was to switch off the air condition temporary for the most sensitive measurements resulting in a gradual temperature increase in the TH warming W7-X and subsequent displacements.

The removal of the temporary supports of MB (1 support for each of the 5 modules) took place sequentially. Thus, monitoring of removal process could be realized by one LT only. To get the most accurate results (0.1 mm for repetition measurements) the LT was not moved during the removal process of a particular support. At each support location 5 targets on the MB, 2 on OV and 2 on PV were obtained and co-ordinates were provided to the engineering group for deeper analysis.

Evacuation and venting of the cryostat were monitored using 25 targets on OV and 17 targets linked to the PV through supply ports. The locations of the targets had been preselected by the engineering group on conditions that approx. 70% of the points are at locations with high and 30% of the point at locations with only small deformations due to vacuum load changes. An additional requirement was to have the points distributed on all 5 modules as symmetric as possible. In reality those conditions could be fulfilled only partially using points on the upper hemisphere of the cryostat. The main restrictions were a limited number of LTs available and very restricted access due to intensive assembly activities close to the cryostat. Finally 3 LTs were used for the global survey of the cryostat whereas one additional LT was used to monitor a special sensitive OV location in real-time during the entire evacuation/venting process.

3.2. Removal of temporary MB supports

As the assembly of the peripheral systems continued it was eventually required to remove all temporary supports (TS) that were in place to support the assembly of the basic machine. Among several temporary supports for the magnet and cryostat system 5 TS were installed below the 5 outer MB supports. Removal of the TS would induce sag of several mm in the outer support beams of the MB resulting in sag of the supported OV and PV. This would introduce additional inaccuracies in the position of in-vessel components already installed in the PV (wall panels, diagnostic etc.). To counteract this sag, it was decided to hydraulically lift the outer support up as such that, after fixation of the diagonal beam (Fig. 1) and release of the applied hydraulic load, the whole system would return to the same position as with the TS installed. The GMCS was used to predict the required hydraulic load and vertical

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