Design Analysis and Manufacturing of the cooling lines of the in vessel components of WENDELSTEIN 7-X

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All In-Vessel Components (IVCs) of W7-X are actively cooled. Inside the plasma vessel about 4 km of pipes will be installed, supplying water to the IVC. 226 cooling circuits with 78 variants are necessary. The cooling circuits enter the cryostat and the plasma vessel through ad hoc flanged penetrations called “plug-ins”, which provide for the vacuum boundary between the plasma chamber and the torus hall atmosphere. The plug-ins are installed inside the W7-X ports. Some of the plug-ins are also used for the diagnostic cables. In total eighty plug-ins will be produced and installed. The inlet / outlet cooling lines are connected to the plug-ins using a welded hydraulic connector. The lay-out of the cooling lines is rather complex in consideration of the limited space and the routing between many component parts. Additionally the differential thermal expansion of the lines with respect to the supporting structures during the different operation scenarios had to be compensated by ad-hoc supports and adjustments in the flexibility of the lines.

Keywords: W7-X, in vessel components, design analysis, manufacturing

1. Introduction

The installation of actively cooled in vessel components (IVCs) is mandatory for the steady-state operation of the stellarator WENDELSTEIN 7-X (W7-X) [1]. The heating power is 10MW over a pulse length of up to 30 minutes and can reach peak loads up to 20MW for 10 seconds. The IVCs protect against thermal loads on the plasma vessel, which has a limited cooling capability.

W7-X has 244 ports and eighty of these are dedicated to the cooling of IVCs. The cooling circuits cross the cryostat and enter the plasma vessel through ad hoc flanged penetrations called “plug-ins”, which are installed inside the dedicated W7-X ports. The inlet / outlet cooling lines of the different IVCs are connected to the plug-ins using a welded hydraulic connector. The limited available space and the 3D shape of the vessel results in a complex routing of pipes. The design is at present in the final stage, the design and on-going manufacture of the IVC cooling system in the plasma vessel are presented.

The machine will start operation with short pulse duration plasma discharges [2] but the design of the cooling circuit will not be modified for this first stage. The cooling system will be used at a reduced level and many water pipes will not be connected to their IVCs.

2. Layout

W7-X has a helix-like magnetic axis with a strong variation of the plasma cross-section. The magnetic configuration has five field periods which define five modules of the machine. Each module is divided in two half-modules, which have an 180° mirror symmetry. The design of the IVCs follows this symmetry. In each half-module, eight ports are available for the supply the different IVCs. Fig. 1 presents the IVCs arrangement and the plug-ins for one machine module. Different types of plasma facing components (PFCs) have to be cooled: divertor target modules, baffle modules, heat shields and panels of the first wall protection. The detailed description of these components can be found in [3]. The major differences between these components are the cooling conditions such as the velocity and the operating pressure as a consequence of the different loadings: 10 m/s and 2.8 MPa for the targets, 6 m/s and 2.5 MPa for the baffles and heat shields, 2 m/s and 2.5 MPa for the panels. The actively cooled targets will not be installed in the initial phase of operation.

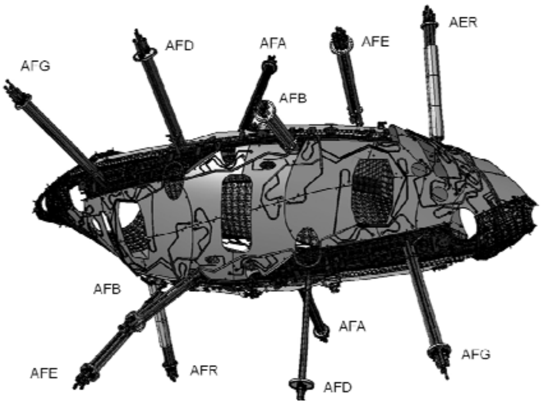

Fig.1 Location of Plug-ins and arrangement of IVCs. The plasma vessel is not shown.

Plug-in name	Targets	Baffles	Heat shields	Panels
AFA	0	4	1	2
AFB	4	2	2	2
AFC	4	0	2	0
AFD	4	2	0	0
AFE	4	2	2	1
AFF	2	2	3	0
AFG	4	2	1	1
AER	0	0	5	4
Sum	22	14	16	10

Table 1: number of PFCs cooling circuits (inlet & outlet) per plug-in for a half-module as a function of the PFC.

In addition, the ten control coils are actively cooled by a special plug-in which includes the electrical supply. The diameter of the ports is 200mm, except AFC and AFD which are ovals. The inner diameter of the cooling tubes in the plug-in varies from 10 to 34mm. Fig.2 is an example of the arrangement of the cooling circuit in a plug-in (AER). The maximum number of cooling pipes is nine and space is very restricted.

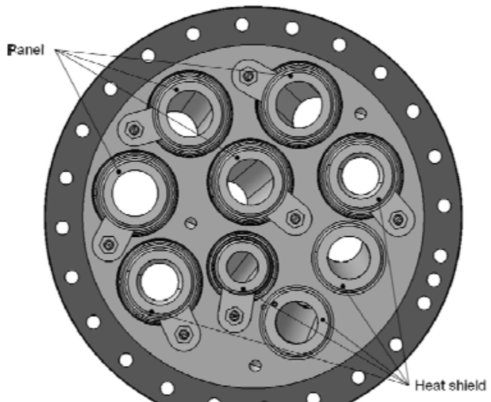

Fig.2 Arrangement of cooling circuit in AER plug-in.

Altogether 226 cooling circuits have to be installed. The geometrical symmetry of the machine is disrupted by the asymmetric locations of diagnostics and heating systems. The design of a cooling circuit is hence specific for each half-module of the machine. Consequently, the number of variants is increased up to 78 rather than 21 (without target cooling circuits) for a fully symmetric machine.

3. Design

Every cooling loop within the vacuum section of the experiment consists of the plug-in in the port and the cooling circuits to the component (inlet and outlet) in the plasma vessel. PFCs are mainly supplied in parallel to reduce the total pressure drop. At the flanges of the plug-in, the maximum pressure drop is 1 MPa and 1.4 MPa, for the baffles, heat shields, panels and for the targets, respectively. The maximum allowed temperature increase between inlet and outlet is 50K. The cooling system has been designed to allow the different modes of operation of the machine [4]. Fig. 3 illustrates the design of the cooling circuit in the case of the panels of the first wall. Panels are transparent to show the underlying circuit.

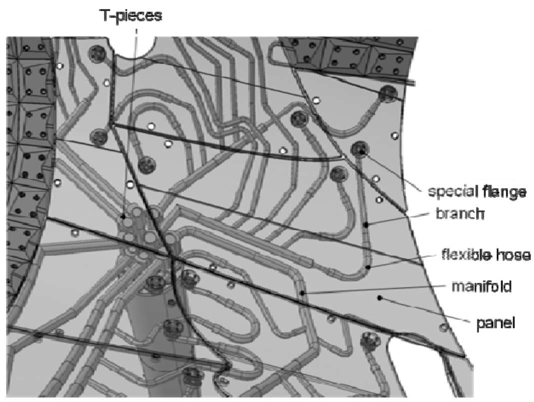

Fig.3 Cooling circuits connected to the supply Plug-in

In each cooling circuit, manifolds distribute the cooling water to the individual components via supply branches. To minimize pressure drop the branches are connected to the manifold with an angle of 60° in the flow direction. A branch is the line between the manifold and the panel. It includes a pipe, a flexible hose and a special flange for the connection to the panel. The circuit has a 3D shape to fit the geometry of the plasma vessel. The inner pipe diameter is 12mm with a wall thickness of 1mm. Flexible hoses allow the flexibility required for connection of the components during installation. Special connection flanges have been developed to compensate small angular installation errors. The cooling circuits have been designed to achieve a balanced flow distribution between components with the required water velocity in the panels. When necessary, orifices are installed.

The cooling circuits are connected by means of welded T-pieces to the plug-ins. This connection required significant design effort due to the lack of space between the plasma vessel and PFCs, the 3D shape of the vessel, the number of various diagnostics inside the vessel including the cabling, and the number of pipes per plug-in. In addition, easy installation and removal is required. T-pieces allow the welding from the accessible front side, performed partly by internal orbital welding and partly by TIG welding (Fig.4). This solution simplifies the mounting of the components in the limited available space for installation with general poor accessibility.

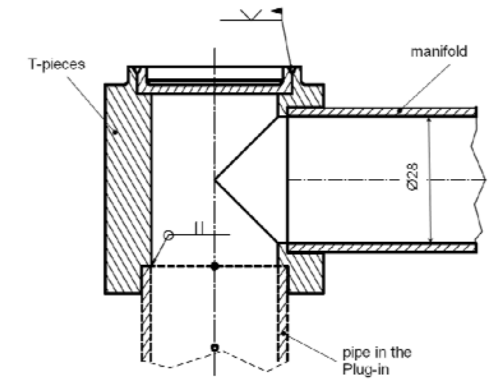

Fig.4 T-piece, connecting the Plug-in pipe to the cooling circuit manifold.

For hot liner operation (plasma operation with a first wall at 150°C), thermal expansion of both cooling circuits and plug-ins has to be allowed. Fig.5 shows the selected designs. In the plug-ins the thermal expansion of the long straight pipes is controlled by fixing the plasma vessel end and allowing expansion outwards, copper bushes located at the flanges prevent fretting of the pipe in the flange. The vacuum barrier against atmosphere is achieved by bellows between pipes and flanges. For the manifolds inside the plasma vessel, the same solution with copper bushes was adopted. Long branches are attached with thin clamps, made of 1.5 mm thick steel, allowing sufficient flexibility.

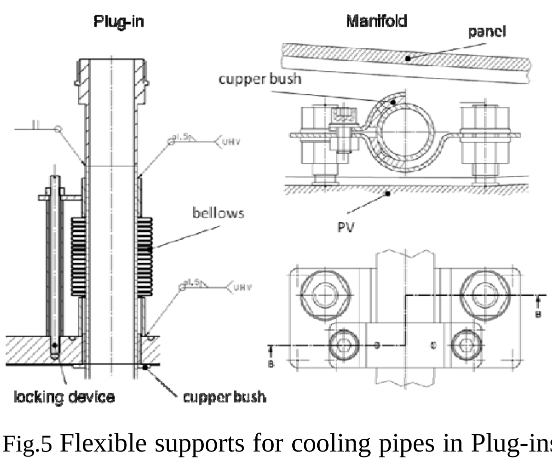

Fig.5 Flexible supports for cooling pipes in Plug-ins (left) and for manifolds (right)

4. Manufacturing

All parts of the cooling circuits are made of stainless steel (1.4441 for 12mm diameter and 1.4435 for other pipe diameters and 1.4429 for other parts) with a low cobalt content of 500 ppm required by W7-X. The cooling circuits are not visible from the plasma side and located between the rear side of the components and the plasma vessel. Access to the cooling circuits after installation will only be possible by dismantling of the IVCs. In addition, the 4 km of pipework is installed in a high vacuum environment. Therefore, high attention was placed on a robust, leak tight solution and the avoidance of any potential for corrosion. Most of the time during no plasma operation, water will flow at a reduced velocity.

The manifolds were procured from the company Dockweiler, Germany. This company developed a special technology to equip manifolds with junctions of different diameters and at different angles, based on "collaring"-technology (Fig.6). This solution allows inside welding of branch stubs to avoid gaps.

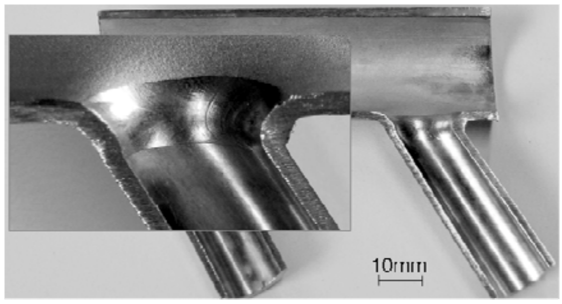

Fig.6 Branch stub, welded from inside to the junction on manifold.

For the design of the cooling circuits, the orbital welding solution was specified from the beginning. The assembly of the circuits was designed and carried out by the IPP.

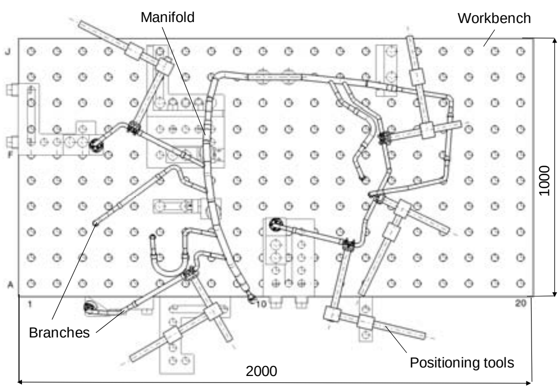

Fig.7 Manufacturing of the cooling circuit.

Due to the complex 3D geometrical shape the cooling circuits are built of bent pipe sections. All pipes are measured by photometry. The achieved accuracy is ±0.75 mm. Assembly of manifolds and branches was performed in special designed assembly jigs. (Fig.7) These jigs are based on standard welding assembly tooling equipped with individually designed adjustable connection and positioning elements. The jigs are assembled with high accuracy to guarantee the correct 3D shape of the circuits. However, the available space inside the plasma vessel and the PFCs, and in the region of the plug-ins is extremely restricted. The circuits have to fit precisely into their positions. Therefore, it was decided to deliver the cooling circuits as semi-completed sets with adaptation pieces. The size of the assemblies is also restricted by the size of the access port through which the components will be moved into the vessel. This design was performed for each of the 78 variants. Before delivery, all assembled parts are leak tested (Fig. 8). This test will be repeated in situ at the final assembly stage inside the plasma vessel.

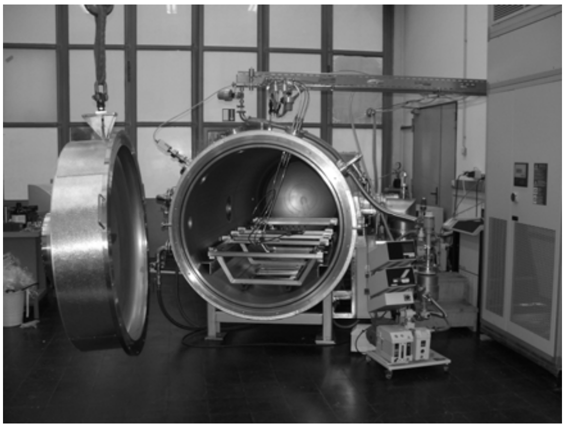

Fig.8 Leak testing facility for all IVCs (IPP-Garching.

4. Conclusion

226 cooling circuits with 78 variants supply the 1500 IVCs of W7-X. They enter the plasma vessel using the port penetrations of the cryostat and the in tube assemblies called “Plug-ins”, which provide for the vacuum boundary between the plasma chamber and the torus hall atmosphere. Eighty of the 244 W7-X ports are dedicated to the cooling of IVCs. The design of the cooling circuits is complex due to the 3D shape of the plasma vessel, the restricted space between the IVCs and the vessel, the asymmetrical locations of heating systems and the different locations of various diagnostics. T-pieces connect the cooling circuits to the plug-ins. Manifolds allow the parallel distribution of the cooling to the IVCs. Flexible hoses are required for the assembly and thermal expansion. To cope with the different modes of operation of the machine, special solutions have been developed to take into account the thermal expansion of the circuits. This complex network of cooling lines will be completely installed right from start of operation although many cooling circuits will not be supplied for the initial phase of short pulse plasma operation.

References

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