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Thermo-structural Development of the ITER ICRF Strap Housing Module

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Abstract. Since March 2010 the preliminary design of the ITER ICRF Antennas have been developed by CYCLE, a consortium consisting of IPP (Garching), CCFE (Culham), CEA (Cadarache), Politecnico di Torino (Torino) and LPP-ERM/KMS (Brussels). This paper describes the steps taken to develop the present geometry of the triplet pair Strap Housing Module from a thermal and structural perspective, and shows the critical areas of the structure. Key issues are the manufacturability, (achieved by HIPing - Hot Isostatic Pressing), the ability to handle the radiating plasma thermal flux of 0.35 MW/m², the RF losses and the neutronic radiation. HIPing is necessary to achieve the complicated system of cooling channels inside the structure, which divides the coolant equally in order to supply each strap in the triplet with 1 l/s of water. The components have also to withstand the strong mechanical forces generated by plasma disruptions affecting all internal structures and the elevated design cooling water pressure of 5MPa. In order to maximise reliability, joints between different materials in the cooling water system have been kept to a minimum. Therefore, in the interests of fabricability and availability, the whole structure is manufactured out of stainless steel (316L(N)IG). The low conductivity of 316L(N)IG demands small wall thicknesses to avoid hot spots; however this reduces the mechanical strength. Consequently an in depth FEM analysis is presented, which was used to find and to improve the critical aspects of this important component and was the best means of finding the optimum between thermal and mechanical performance.

INTRODUCTION

Each of ITER's ICRF Antennas is designed to couple 20 MW of RF power into the plasma [1] and consists of 4 modules with 6 straps each. Each module disposes of two vacuum transmission lines, which feed 3 straps each via a so called 4 port junction. The component of concern in this paper is the Strap Housing Module. This module is housing the straps behind the faraday screen in the overview picture Fig. 1. Its major function is to provide mechanical support to the radiating straps, to supply them with cooling water and to be part of the return conductor of the RF system. The faraday screen is mechanically mounted on top as well, but disposes of its own water supply.

In order to supply the straps with cooling water, the coolant flow is divided in two equal parts and distributed to the sides. There, after meandering down the side walls, it is equally distributed between the 6 straps. After flowing through the straps and the attached 4 port junction, the water is re united in the middle wall of the housing component, where it is sent back to the coolant manifold.

The whole part is manufactured out of stainless steel (316L(N)IG) with a thin copper coating on top to improve the electrical conductance at high frequencies.

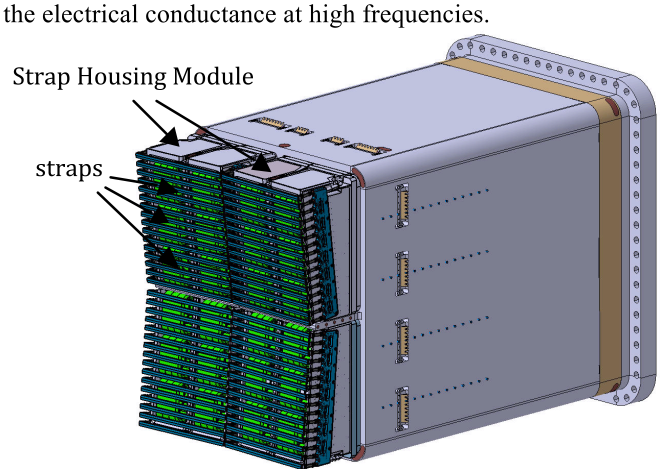

FIGURE 1. Overview ITER ICRF Antenna.

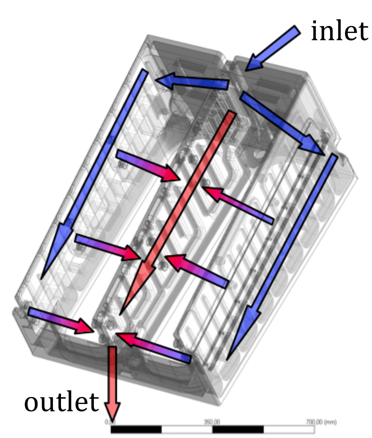

FIGURE 2. Flow distribution Strap Housing Module.

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SIMULATION

Thanks to the largely symmetrical geometry, it could be split in half with a symmetry plane in the middle, in order to simplify the simulation. The straps and the 4 port junction are developed separately, but form part of the water flow in this component, so they have been replaced by a simple tube in order to guarantee a continuous water flow. The heat flux from the plasma is expected to be 350 kW/m². The average shielding of the faraday screen is calculated to be 68.8%, so the incoming heat flux on the plasma facing surfaces is estimated to be 109kW/m². According to Mark Vrancken there are going to be RF losses in an image of the straps on the inner surface of the housing modules of approximately 120 kW/m² [2]. As this value is superposed by the plasma radiation, a conservative heat flux of 250 kW/m² is assumed in this area. A neutronic analysis has been conducted by Andrew Davis from CCFE using MCNP [3], but the generated data of neutronic heating in this component contains a big factor of uncertainty. So for security his results have been multiplied by a factor of 3 and then imported into the CFX model (Fig. 4). Additionally on the surfaces, which are not directly but indirectly plasma facing, a uniform heat flux of 50 kW/m² was added (Table 1). The whole antenna is designed to deliver 1 l/s water to each strap. As only one half of the model is considered, a water flow rate of 3 l/s was applied to the cooling channels. In a single simulation the flow- and the steady-state temperature distribution (Fig. 5) has now been calculated in Ansys 14.0 CFX [4]. This temperature distribution with a maximum of 435°C leads to thermal stresses, which are accompanied by stresses due to the elevated design cooling water pressure of 5 MPa. These stresses have also been calculated in Ansys by importing the temperature distribution into an Ansys steady state structural simulation and adding the coolant pressure manually. This loadcase is called "normal operation condition" NOC and is shown in Fig. 6. A disruption analysis has also been performed, containing the Strap Housing Module, the straps and the 4 port junction. This analysis showed, that the maximal mechanical stresses appeared in the straps and the stresses in the Strap Housing Module were minor to the materials tensile strength. In order to eliminate hot spots and concentrations of thermal stresses, all plasma facing areas have been rounded and edges have been removed in favour of big radiuses of at least 10mm.

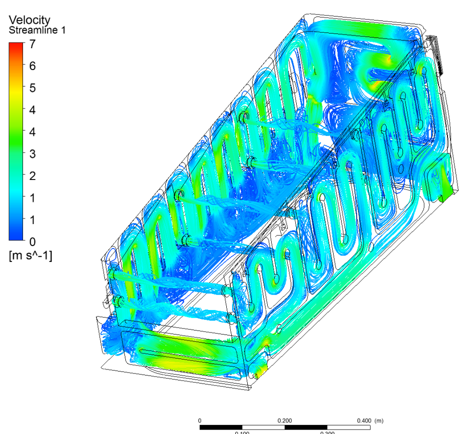

FIGURE 3. Flow distribution.

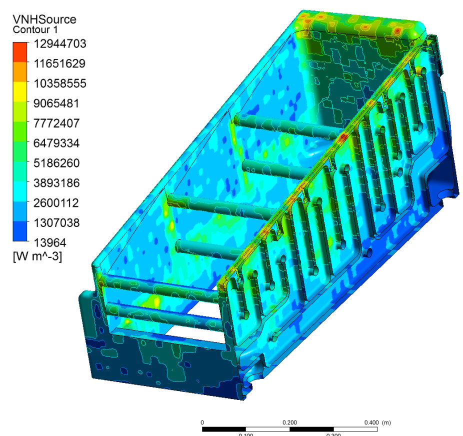

FIGURE 4. Neutronic heating.

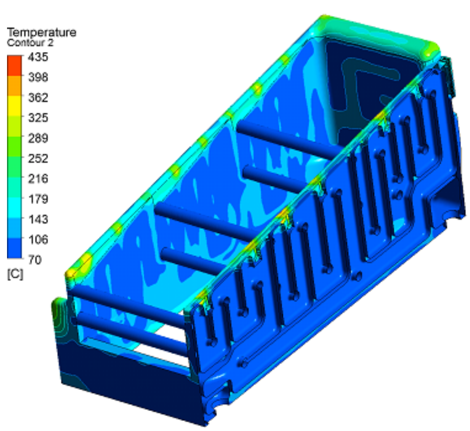

FIGURE 5. Temperature NOC.

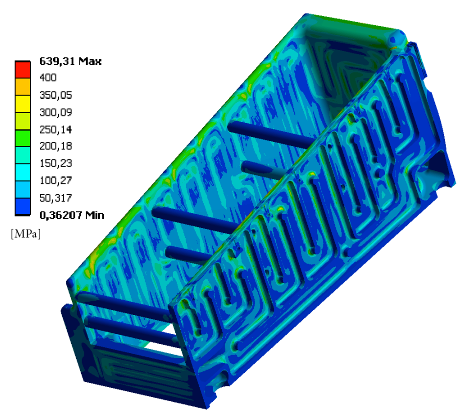

FIGURE 6. Neutronic heating.

TABLE 1. Thermal loading.

neutronic heating	3 x imported data
directly plasma facing surfaces	uniformly 109 kW/m²
indirectly plasma facing surfaces	uniformly 50 kW/m²
surfaces with strong RF losses	uniformly 250 kW/m²

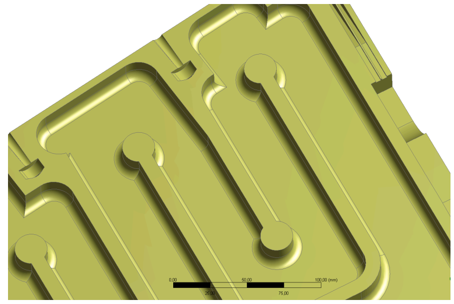

FIGURE 7. Stiffened edges.

The regions showing the highest stresses now in normal operating condition were with 437 MPa the ends of the septum walls dividing the cooling channels in the side walls. As these stresses disappeared in a similar simulation without applied cooling water pressure, it is obvious, that they are caused by the side plates trying to buckle due to the internal pressure. So these regions have been stiffened by introducing columns. The columns reduce the stresses in these areas to 370 MPa. The highest stress occurs now in the joint between the middle and the top plate. By running the same simulation without the thermal load, these stresses disappear and therefore are purely thermal. Due to the ductility of stainless steel, thermal stresses are putting the structural integrity of this component less at risk than the ones emerging from the water pressure.

MANUFACTURING

Several geometries with different manufacturing routes have been evaluated in the past. Due to the complex external shape and the system of internal cooling channels, the manufacturing by HIPing (Hot Isostatic Pressing) has been preferred. Several ITER components like the whole first wall are going to be HIPed.

There are two different procedures of producing a part by HIPing [5].

The first method (Fig. 8) is to produce an outer capsule in stainless steel (1) and to insert an inner capsule of ferritic steel (2), forming the cooling channels. Now all the remaining empty space in the box has to be filled with stainless steel powder, evacuated and baked at high temperature and high external Argon pressure. This causes the stainless steel powder to sinter and to form a massive body of stainless steel containing the inner capsule of ferritic steel. After removing the outer capsule mechanically, the inner capsule can now be etched out, leaving the sintered metall powder, forming the finished part and containing the desired cooling channels. It looks like a combination of part 3 and 5 in Fig. 9.

The second means (Fig. 9) is not to use a powder, but different solid bodies exactly fitting into each other. Here the sintering process of a powder in a capsule is replaced by a process similar to diffusion welding between solid bodies. Instead of using an outer capsule full of powder, the intention is to bond two solid bodies at all the touching areas. The first step is to produce one half of the finished product with the grooves for the cooling channels already in place (3). In a second step the inner capsule of ferritic steel (4) is machined and inserted in the groove. It is only necessary to prevent the part from collapsing in the process of HIPing. Now the second half of the part (5), in Fig. 9 just a plate, has to be placed and welded unde vacuum on top of the first half in order to form an air tight capsule.

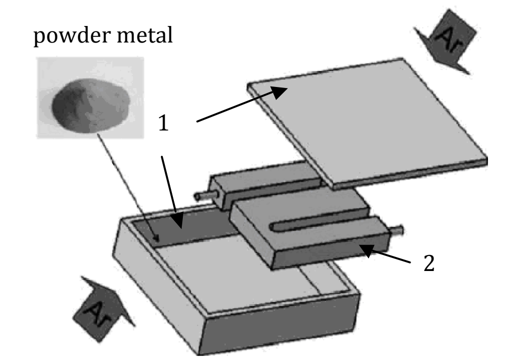

FIGURE 8. Powder HIPing.

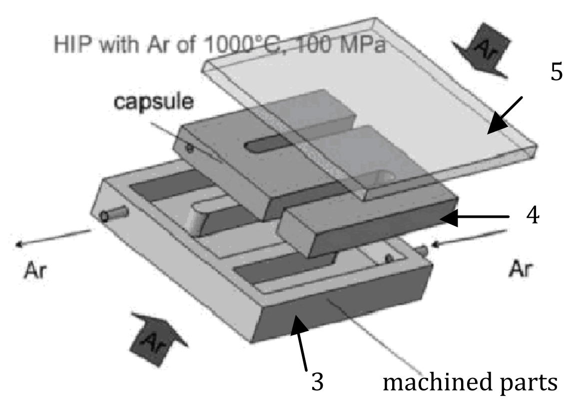

FIGURE 9. Solid body HIPing.

After applying an elevated external Argon pressure at a high temperature, all 3 bodies diffusion weld and form a single solid block.

Now again, the ferritic body forming the cooling channels can be etched out, leaving the finished part.

In the process of sintering in the first method, the part is decreasing in volume. As this decrease is not uniform, the geometry itself is changing unpredictably. Therefore the production technique of choice is a combination of the second method and some conventional deep drilling and welding. The whole geometry and the arrangement of cooling channels has already been designed with this method of manufacturing in mind. The structure consists of several parts which will be milled and then united by HIPing.

The cooling channels are created by the insertion of several bodies, which fill the gaps in Fig. 10.

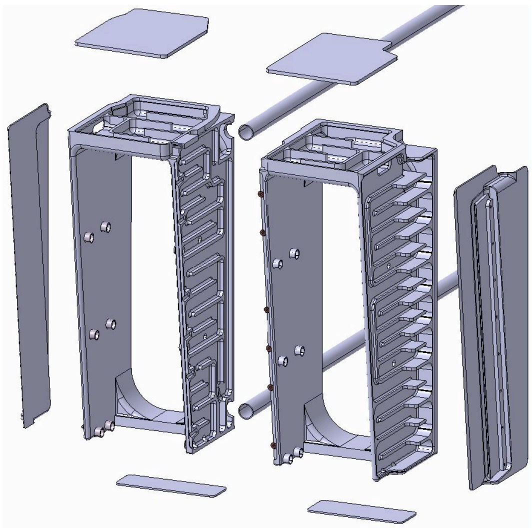

FIGURE 10. Single components before HIPing.

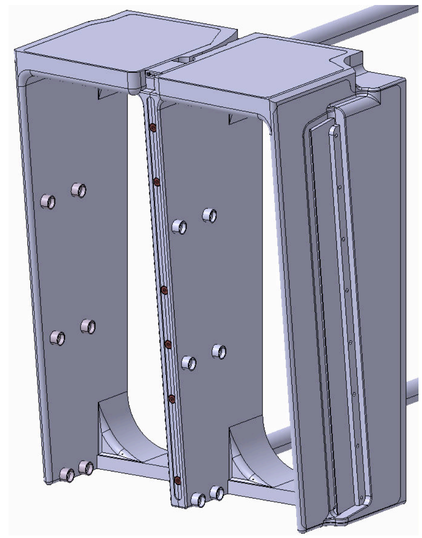

FIGURE 11. Finished Strap Housing Module.

CONCLUSION

A full hydraulic, thermal and mechanical FE analysis of the Strap Housing Module has been conducted. Critical areas have been found and improved. All plasma facing edges have been replaced by radiuses of at least 10mm and the edges of the internal walls dividing the cooling channels have been stiffened.

The presented geometry is going to withstand the elevated cooling water pressure and is able to handle the expected heat loads.

A means of manufacturing has been found and the component designed in order to guarantee manufacturability.

Still further development and tests especially in the field of manufacturing and production are required.

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