ESS CRYOMODULE FOR ELLIPTICAL CAVITIES

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Abstract

The European Spallation Source (ESS) is under development and construction in Lund, Sweden. It will be the world's most powerful neutron source, up to 30 times brighter than current facilities [1]. For this purpose, a 5MW linear proton accelerator is used with a 4% duty cycle. The superconducting part is composed of 3 strings of 26 spoke cavities, 36 medium and 84 high β elliptical cavities.

The cryomodules of the two last sections contain 4 elliptical cavities, operating at 2K and 704.42MHz. Within the framework of the international collaboration for this program, CEA Saclay in in charge of the elliptical cavities and couplers developments while IPN Orsay is responsible of the cryomodule design.

This paper presents the overall design and the thermo-mechanical aspects of the cryomodule for elliptical cavities. A prototype (ECCTD, Elliptical cavity cryomodule Technology Demonstrator) will be built and tested in order to validate the design and the solutions implemented.

INTRODUCTION

ESS Programme

The European Spallation Source (ESS) is a multi-disciplinary research center based on the world's most powerful neutron source. After completion, it will improve visualization techniques and enable new opportunities for researchers in the fields of life sciences, energy and environmental technology. It is under design and construction in Lund, Sweden.

ESS Linac

The linear proton accelerator is composed of an ion source, different stages of bunching and pre acceleration, 3 superconducting sections and a heavy metal target (see figure 1). It provides a 5MW beam with a 4% duty cycle (2.86ms pulse at 14Hz). The superconducting part of the linac is composed of 3 strings of 26 spoke cavities (β=0.5), 36 medium (0.67) and 84 high β (0.86) elliptical cavities [2].

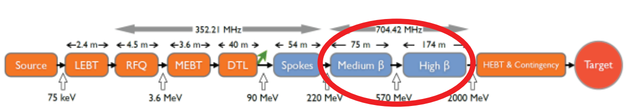

Figure 1 : Linac layout.

Cryomodules for Elliptical Cavities

The elliptical cavities operate at a temperature of 2K and a frequency of 704.42MHz. Each cryomodule houses 4 resonators. Therefore the complete section is composed respectively of 9 medium and 21 high beta cryomodules. The cryomodules are connected to the cooling plant by a Cryogenic Transfer Line (CTL) that runs alongside the linac.

CRYOMODULES LAYOUT

Cryomodule Composition

Figure 2 shows the composition of each cryomodule. The 4 cavities are separated by 3 bellows allowing the thermal contraction and the displacements due to the Cold Tuning System (CTS). A cold to warm transition at each extremity ensures low heat losses between the cold mass and outside ambient temperature. A metallic warm valve closes the beam vacuum at each extremity.

There is no focusing magnetic coil inside the vacuum tank.

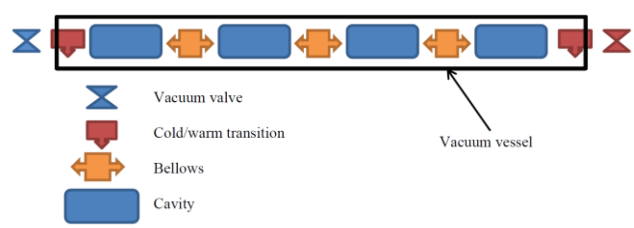

Figure 2: Cryomodule layout.

Medium an High Beta Homogenization

The high beta elliptical cavities are composed of 5 cells and the medium beta of 6 [3]. As a result, the length difference between these two types is only some centimetres. The Cold Tuning System and the helium tank diameter are the same.

Due to this similarity, it has been decided to design similar cryomodules for medium and high beta sections in order to minimize the specifics parts and then the costs, and to have the same external interfaces in the tunnel. It also allows the possibility to replace the first high beta cryomodule of the section by a medium one if necessary.

The following components are the same: vacuum vessel, spaceframe, thermal screen, handling system, most of the cryogenic pipes, tuning system, ceramic windows with antenna, door-knob.

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GENERAL DESIGN

Overview

Due to the length of the cryomodule, it would be very inconvenient to position and adjust the cavities and the thermal screen directly inside the vacuum vessel.

All the hanging and alignment operations of the cavities string and shielding are implemented in a first time inside an intermediate structure, the spaceframe.

This assembly is inserted in the vacuum vessel in a second step.

Figure 3 shows the main components of the cryomodule: vacuum vessel, spaceframe, thermal screen and cavities string.

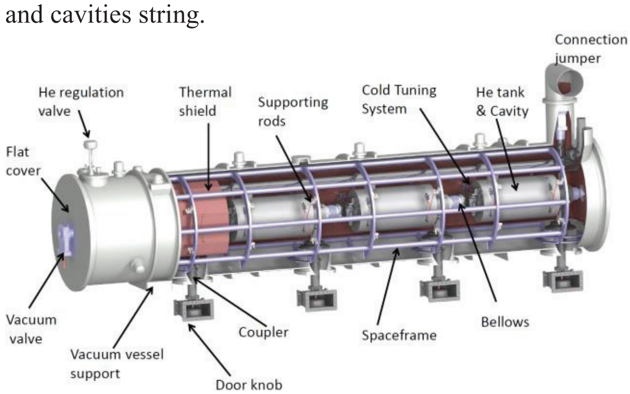

Figure 3: Cryomodule overview.

On the longitudinal cross section, Figure 4, the low pressure cryogenic line is shown above the cavities string and connected to the Cryogenic Transfer Line by a double angled connection, the jumper. RF waveguides are connected underneath the cryomodule, using door-knob transition to the couplers.

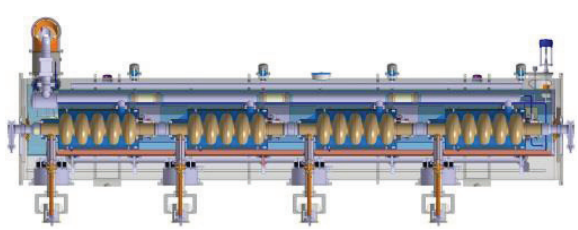

Figure 4: Cryomodule cross section.

Main characteristics [4]:

- Overall length 6600 mm
- Beam axis height 1500 mm
- Overall height 2826 mm from the ground
- Weight 5.8 tons
- Distance between couplers 1500 mm

Hanging and Cross Positioning of the Cavities

Figure 5 shows a cross section of the cryomodule. Each cavity is hanged inside the spaceframe by 2 sets of 4 cross rods. This connection is made before the introduction of the whole assembly inside the vacuum vessel. The thermal shield is also hanged to these rods by the mean of aluminium “elastic boxes” that allow the thermal shrinkage while maintaining the transverse stability. Thus the 50 K thermalization of the rods is ensured by the thermal shield at about 2 thirds of the length. The rods are linked to titanium half rings positioned around the helium tank and below the magnetic shield. The use of titanium instead of steel avoids any magnetic issue on the beam. An insert ensures a rotating joint at this connecting point. On the other side, the rods are linked to the spaceframe at ambient temperature.

The rods are made of TA6V, a titanium alloy that have both high mechanical and thermal characteristics. The diameter is 6mm and the length 490mm.

A 3000N pre stress is applied to maintain the cavities string stability, especially during the transportation between the assembly premises and the final location.

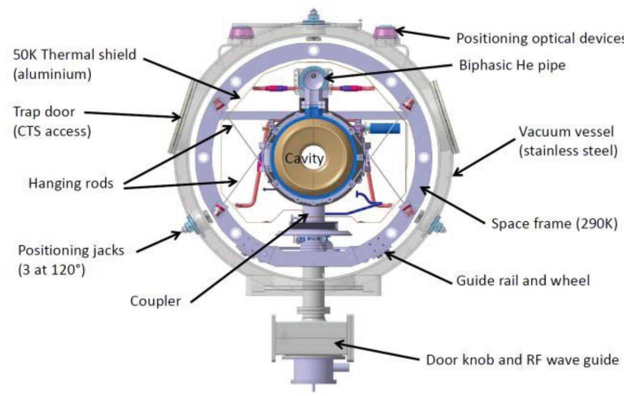

Figure 5: Cryomodule transverse cross section.

Axial Positioning of the Cavities

Axial positioning by rods would have many constraints: difficulty to ensure the position, lot of holes on thermal and magnetic shields. A different system has been chosen.

A first axial positioning is performed before the introduction of the assembly inside the vacuum vessel by the mean of different rods screwed to the tank on one side (half ring for cross rods), and fixed with an adjustment to the spaceframe on the other side.

After insertion inside the vacuum vessel, the coupler flanges are jammed with 2 thin stainless steel plates that fix the axial position but allow a vertical motion needed for the thermal contraction. Then, the axial rods are removed before closing the vacuum tank.

Spaceframe

The spaceframe is composed of 8 rings connected each other by 7 welded pipes (Fig. 6). The rings are opened at the bottom in order to insert the cavities string in the spaceframe and then closed by steel parts ensuring a high stiffness. The rings are made of aluminium that has a high thermal conductivity and then ensure good temperature stability at 290K by means of different thermalization points with the vacuum vessel. The spaceframe is positioned inside the vacuum vessel and blocked by 5 levels of 3 jacks at 120° in order to limit its displacements due to the weight and the stress induced by the rods (see figure 7).

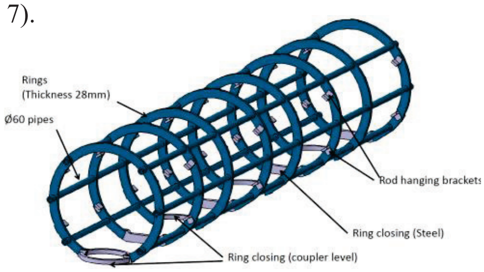

Figure 6: Spaceframe.

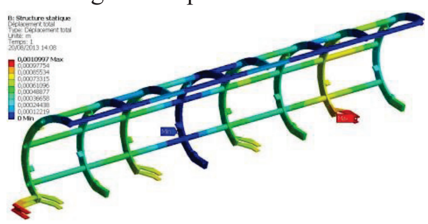

Figure 7: Displacement of the spaceframe.

Thermal Shield

The thermal shield (Fig. 8) is made of 2.5mm thick aluminium. It is fastened directly to the support rods of the cavities string. This configuration limits heat losses by conduction. Multi-layer insulation is wrapped around the shield. 8 movable panels in front of the Cold Tuning System allow the access for the replacement of failed motors or other fragile parts like piezo stacks.

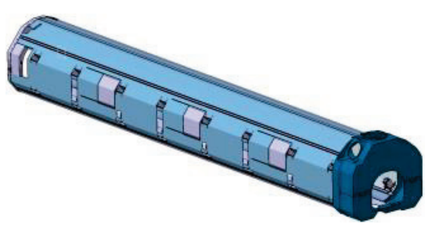

Figure 8: Complete thermal shield.

Cold to Warm Transition

The cold to warm transition (Fig. 9) ensures the link between the 2K cavity and the outside beam pipe at ambient temperature. In order to limit the heat losses by conduction, the wall thickness is limited to 1.5 to 2mm and a bellows is inserted to increase the thermal resistance and also compensate the thermal shrinkage and the geometric defaults. The bellows protects also the cavity flange from atmospheric pressure force. Figure 10 shows the temperature distribution.

It is made of stainless steel.

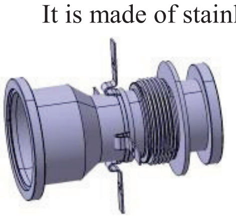

Figure 9: Cold/warm transition.

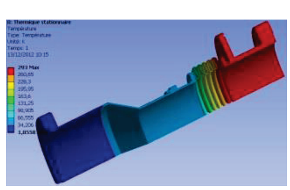

Figure 10: Cold/warm transition temperature map.

Vacuum Vessel

The vacuum vessel is made of 10mm thick stainless steel (Fig. 11). It rests on the ground by means of two support blocks. It is closed at each extremity by two flat covers. Eight trap doors allow an access to the cold tuning system to remove failed parts.

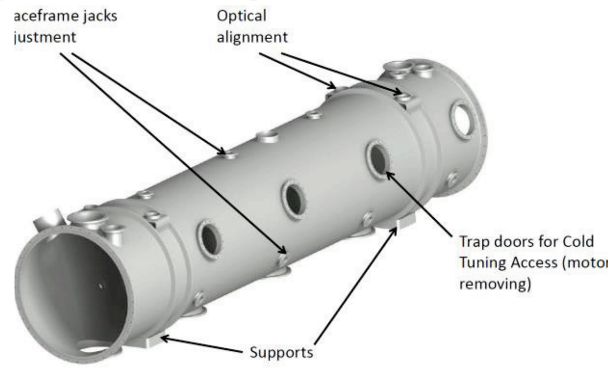

Figure 11: Vacuum vessel.

GENERAL ASSEMBLING PROCEDURE

The cavities string is assembled in a clean room. It comprises the resonators, the helium tanks, the bellows, the cold/warm transitions and the vacuum valves. The pre-alignment of the cavities is made during this phase.

Outside the clean room, the different cryogenic pipes are welded or screwed directly to the cavities string. The cold mass is equipped with the tuning system, the magnetic shield, the instrumentation components… At the same time, the main section of the thermal screen is temporarily fastened to the spaceframe.

In the following step, the equipped cavities string is inserted inside the spaceframe as shown in figure 12. The bottom of the spaceframe is closed to strengthen all the structure.

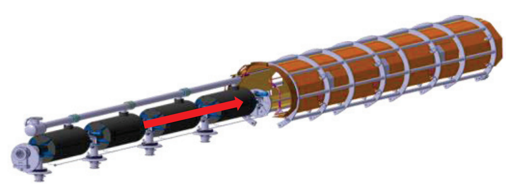

Figure 12: Insertion of the cavities inside the spaceframe.

All these operations are based on the use of different rail systems that support and guide the cavities string, the thermal screen and the spaceframe.

During the first step of the operation, the supporting transverse rods are screwed on the helium tanks and connected to the spaceframe on the other side where the 3000N pre-stress is applied by means of a spring and screw device. The thermal screen is fixed to these rods at 2 thirds of the height while the temporary link is removed.

The axial position of each cavity is temporarily adjusted and fixed by means of 4 rods fastened to the helium tanks on one side and blocked to the spaceframe extremities on the other side.

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All the assembly is moved inside the vacuum vessel by means of a wheel device fixed to the spaceframe and rolling on two rails welded on the vessel wall.

All the assembly is aligned and blocked. The position of each power coupler is axially fixed by 2 thin plates fixed between their flange and the vacuum vessel. The temporary device can be removed.

Then, all the final operations can be carried out: installation of second sections of the couplers and RF door knobs, welding of the cryogenic circuit at each extremity, closing of the thermal shield, assembly of the connection jumper to the cryogenic transfer line…

CONCLUSION

A technology demonstrator shall be built to validate the design and the industrialization for series production [5].

The ESS cryomodule for elliptical cavities is under design within the framework of France's in-kind contributions. The 2 laboratories involved are CEA/IRFU for the resonators and couplers, and CNRS/IPNO for the cryomodule alone. The project is the product of this collaborative effort.

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