MANUFACTURING STATUS OF THE IFMIF LIPAc SRF LINAC

N. Bazin#, G. Devanz, S. Chel, H. Jenhani, O. Piquet, A. Bruniquel, A. Riquelme, P. Charon, G. Disset, P. Contrepois, P. Hardy, J. Chambrillon, N. N'Doye, J. Relland, B. Renard, J. Plouin, C. Boulch, D. Roudier, P. Carbonnier, CEA/DRF/IRFU, Saclay, France
F. Toral, D. Regidor, CIEMAT, Madrid, Spain

Abstract

This paper gives the status in the manufacturing of the IFMIF cryomodule. This cryomodule will be part of the Linear IFMIF Prototype Accelerator (LIPAc) whose construction is ongoing at Rokkasho Fusion Institute, Japan. It is a full scale of one of the IFMIF accelerator, from the injector to the first cryomodule. The cryomodule contains all the necessary equipment to transport and accelerate a 125 mA deuteron beam from an input energy of 5 MeV up to the output energy of 9 MeV. It consists of a horizontal vacuum tank of around 6 m long, 3 m high and 2.0 m wide, which includes 8 superconducting HWRs for beam acceleration, working at 175 MHz and at 4.45 K, 8 Power Couplers to provide RF power to cavities up to 70 kW CW in LIPAc case and 200 kW CW in IFMIF case, and 8 Solenoid Packages as focusing elements.

THE IFMIF LIPAC SRF LINAC

The IFMIF LIPAc SRF Linac mostly consists of one cryomodule designed to be as short as possible along the beam axis to meet the beam dynamic requirements. As depicted in Figure 1, it is made of a rectangular section vacuum vessel, a warm magnetic shield, a thermal shield cooled with helium gas. A titanium frame supports the cold mass made of a cylindrical phase separator with cryogenic piping, the cavities and the solenoids.

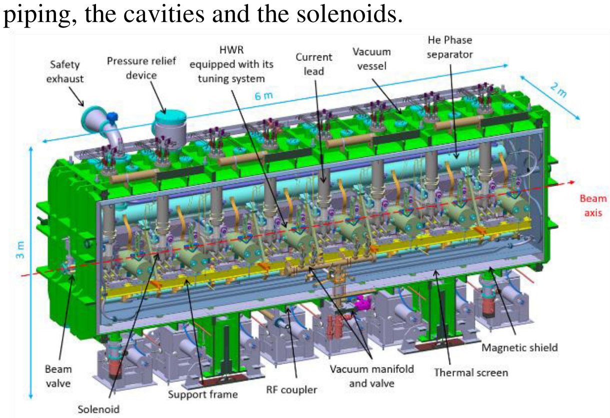

Figure 1: The IFMIF LIPAc cryomodule.

More details on the design of the cryomodule as well as the development plan and the actions taken to mitigate some risks are detailed in [1]. The next sections will present the manufacturing status of the main components of the cryomodule.

CAVITY STRING COMPONENTS

Cavities

The status of the manufacturing and tests of the cavities is presented in [2].The first manufactured HWR has passed low power tests at 4.2K in vertical cryostat successfully and exceeds the specifications (Figure 2). It has also been tested in the dedicated horizontal Sathori cryostat equipped with its cold tuning system. The serial production and qualification tests of the eight cavities which will eventually equip the cryomodule are carried out in parallel.

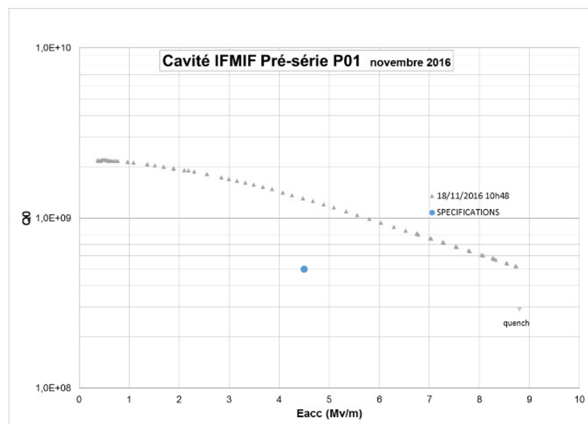

Figure 2: Vertical test results of the first manufactured HWR.

Power Couplers

The design of the power couplers is presented in [3]. Two couplers were delivered at CEA in April 2016 [4], but had to be reworked by the manufacturer due to imperfections. Additional controls and tests were implemented during the manufacturing process and the Factory Acceptance Tests of the eight power couplers occurred between November 2016 and April 2017.

The first pair of power couplers is now ready for the RF conditioning by CIEMAT after being prepared in clean room at CEA Saclay and assembled on the coupling cavity in Spain (Figure 3).

The second pair is being prepared in clean room before being shipped to CIEMAT, and the third and fourth pairs will follow in the next few weeks.

Contact: nicolas.bazin@cea.fr

ISBN 978-3-95450-182-3

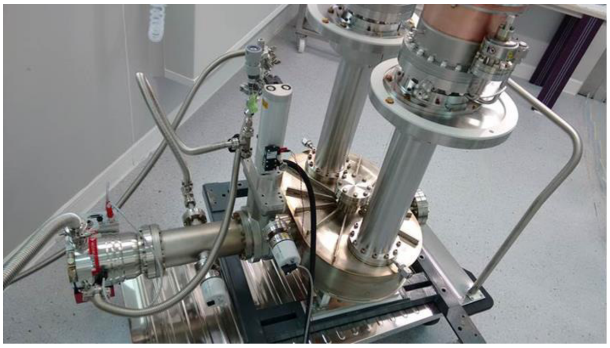

Figure 3: The first pair of power couplers assembled on the RF coupling cavity.

COMPONENTS OF THE CRYOMODULE

Vacuum Vessel

The vacuum vessel is a hollow rectangular cuboid with a door on each ends and four trapdoors on each lateral sides (Figure 4). The vacuum vessel is made of stainless steel and the trapdoors in aluminium. The manufacturing of such a vessel was challenging as several ports in interface with devices of the cold mass had to be precisely positioned (ports for the power couplers, the current leads and the vertical and horizontal tie rods).

Several controls and tests were performed on the vacuum vessel at the manufacturer's premises: a hydrostatic pressure test followed by a leak test, and a dimensional control. Despite minor non conformities on the baseplates (see next section), the vacuum vessel has been accepted and is now at Saclay, ready for shipment to Japan.

Figure 4: The vacuum vessel.

Magnetic Shield

In order to avoid trapping magnetic flux while cooling down through transition, the superconducting cavities are protected against the background magnetic field by a warm magnetic shield which is attached to the inner surface of the vacuum vessel. The shield is made a 2 mm thick mu-metal panels which is sufficient to get a static field of 2 µT at the cavities locations [5].

The panels are installed on baseplates which are welded on the inner surface of the vacuum vessel. Holes are threated in the baseplates for the connection of the shield panels. After the manufacturing of the panels and before heat treatment, a blank assembly of the shield in the vessel has been performed at CEA. Due to minor manufacturing defects of the vacuum vessel, some holes in the panels had to be enlarged and special washers manufactured [6].

The magnetic shield has been successfully installed in the vacuum vessel after heat treatment of the panels (Figure 5). Magnetic measurements have been performed and the static field is under the specifications of 2 µT.

Figure 5: Magnetic shield installed in the vacuum vessel.

Phase Separator

All components containing helium gas or liquid during operation of the LIPAc have been designed, and are fabricated and tested according to ASME standards, as agreed in the collaboration to meet the Japanese regulatory requirements with regard to HPGSL (High Pressure Gas Safety Law) [1].

The phase separator is one of the components which have to respect the ASME Boiler and Pressure Vessel Code (BPVC). It ensures the storage, separation of liquid helium (LHe) and gaseous helium (GHe) and its distribution to the components of the cryomodule. It is a 5200 mm long and 206 mm diameter cylindrical vessel made of stainless steel with more than 30 openings connected to the cavities, the solenoid packages and the power couplers (Figure 6). It is attached to the support frame thanks to five titanium supports.

The manufacturing of this device is now finished. A pressure test of the phase separator was performed in presence of a third party inspector in April 2017. It has been followed by a helium leak test.

Figure 6: The phase separator at the manufacturer's premises.

Thermal Shield

The thermal shield is made of several aluminium panels with pipes welded on them. Only the piping shall be ASME B.31.3 "Process Piping" compliant.

The manufacturing of the thermal shield is now finished. Pressure tests of the piping was hold in presence of a third party inspector in the manufacturer's premises, as well as leak tests.

A blank assembly of the thermal shield in the vacuum vessel was performed in November 2016, before the welding of the pipes on the panels. After the welding, as the vacuum vessel was not anymore at the manufacturer's premises, only partial assembly tests were performed with the hoses linking different panels (Figure 7).

Figure 7: Partial assembly of two panels of the thermal shield.

Support Frame

The residual magnetic field around the superconducting cavities is a crucial factor for their performance. Even if the magnetic shield protects the cavities against the earth's magnetic field, some components inside the cryomodule could be magnetized by the fringe field of the solenoids. As described in [7], the frame is made of titanium I-beams as experience showed that even when using 316L stainless steel, the permeability of the weld rim may be higher than expected. Moreover, as the frame is used as a support for the assembly of the cavity string in clean room [8], the top surface of the frame is precisely machined after welding to respect the flatness requirement of 0.1 mm/m, and all the surfaces are machined or polished in order to have a good surface finish.

Custom made I-beams have been manufactured last summer. The welding process has been validated on a mock-up, and then the beams cut and welded together to form the frame. The machining is now being performed and the frame shall be delivered in the next few weeks.

CONCLUSION

The manufacturing of the components of the IFMIF cryomodule is well advanced, the vacuum vessel, magnetic shield, thermal shield and separator phase being today at CEA Saclay.

As explained in [9], the cryomodule will be assembled under the responsibility of F4E (Fusion for Energy) with CEA assistance at Rokkasho Fusion Institute, where a cleanroom will be built by QST. In addition to the blank assemblies described in this article, many tests and trial assemblies has been realized on the CEA site of Saclay, France [10].

REFERENCES

[1] H. Dzitko *et al.*, "Technical and logistical challenges for IFMIF-LIPAc cryomodule construction", proceedings of SRF2015, Whistler, BC, Canada, FRBA01.

[2] G. Devanz *et al.*, "Manufacturing and Validation Tests of IFMIF Low-Beta HWRs", Proceedings of IPAC2017, Copenhagen, Denmark, MOPVA039.

[3] H. Jenhani *et al.*, "Input Power Coupler for the IFMIF SRF Linac", Proceedings of IPAC2012, New Orleans, Louisiana, USA, WEPPC001.

[4] H. Jenhani *et al.*, "Manufacturing of the IFMIF Series Power Couplers", Proceedings of IPAC2016, Busan, Korea, WEPMB005.

[5] J. Plouin *et al.*, "CEA experience and effort to limit magnetic flux trapping in superconducting cavities", SRF'15, Whistler, Canada, TUPB100.

[6] N. Bazin, "CEA experience on low beta cryomodules", presentation at the TTC, East Lansing, Michigan, USA, February 2017.

[7] N. Bazin *et al.*, "Magnetic aspect of the IFMIF cryomodule", presentation at the TTC meeting, Tsukuba, Japan, December 2014.

[8] N. Bazin *et al.*, "Development of a test bench to prepare the assembly of the IFMIF LIPAc cavity string", proceedings of SRF2015, Whistler, BC, Canada, TUPB107.

[9] D. Gex *et al.*, "Engineering Issues of the Medium Energy Beam Transport Line and SRF Linac for the LIPAc", Proceedings of IPAC2016, Busan, Korea, WEPMR045.

[10] J. Chambrillon *et al.*, "CEA activities to prepare the assembly of the IFMIF-EVEDA Cryomodule", Proceedings of IPAC2017, Copenhagen, Denmark, MOPVA043.

ISBN 978-3-95450-182-3