# MECHANICAL AND CRYOGENIC SYSTEM DESIGN OF THE FIRST CRYOMODULE FOR THE IFMIF PROJECT

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*Abstract*

The IFMIF-EVEDA project aims to demonstrate the feasibility of a high intensity material irradiation facility and one of its main components is a prototype of a high intensity deuteron accelerator. This prototype will be built in Rokkasho in Japan. It includes a cryomodule composed of 8 superconducting cavities (HWR) powered by 200 kW couplers to accelerate the deuteron beam from 5 MeV to 9 MeV. The beam is focused inside the cryomodule by 8 superconducting solenoids. The cryomodule design has to respect some severe beam dynamics requirements, in particular a restricted space for the component interfaces and an accurate alignment to be kept during cooling down. A double cryogenic supply has been designed as it is necessary to control the cavity cooling independently from the solenoid one. The cryomodule design should also be compatible with its environment in the Rokkasho building. This paper gives a general overview of the cryomodule current design and its interfaces. It presents the concept chosen for the cryogenic systems. It also summarizes the method foreseen for the assembly and alignment and describes the integration scenario in Rokkasho.

## CRYOMODULE DESIGN

### *General overview*

The IFMIF (International Fusion Material Irradiation Facility) project aims to build a high intensity material irradiation facility to develop and test some new materials for the future fusion reactors. The IFMIF high intensity deuteron accelerator (125 mA in continuous wave (CW)) will include 2 accelerating lines with 4 cryomodules but the accelerator prototype only includes the first cryomodule. This cryomodule includes 8 superconducting Half Wave Resonators (HWR) operating at 175 MHz, providing a 4.5 MV/m accelerating field to accelerate the deuteron beam from 5 MeV to 9 MeV [1].

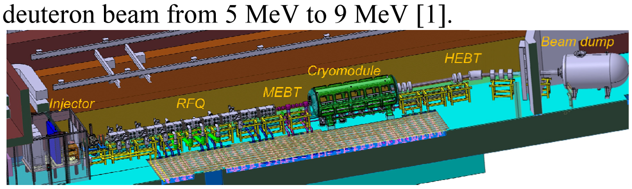


Figure 1: General Layout of the IFMIF-EVEDA accelerator in the Rokkasho vault

It also includes also 8 superconducting focusing solenoids packages with Beam Position Monitors (BPM), a support and its alignment system, some cryogenic and vacuum systems, a thermal and a magnetic shield. The cryomodule is around 5m long, 2m wide and 2.8m high with a mass around 15 tons. The component positions have been defined according to the beam dynamics constraints and the beam axis position fixed for the whole accelerator at 1.5 m above the ground. Inside the cryomodule, the coupler is indeed positioned vertically to limit the mechanical stresses on its ceramic window and the cavity is therefore fixed horizontally. To limit the beam losses due to its high intensity, the cryomodule design has to respect some severe beam dynamics requirements, in particular a restricted space for the component interfaces which have been minimized as much as possible [2]. This cryomodule has also to assure an accurate alignment of the cavities and solenoids, taking into account the thermal shrinking not negligible for such a cryomodule size. The cryomodule will be tested in Europe before being shipped assembled to Japan. Its design should therefore be compatible with the transport constraints.

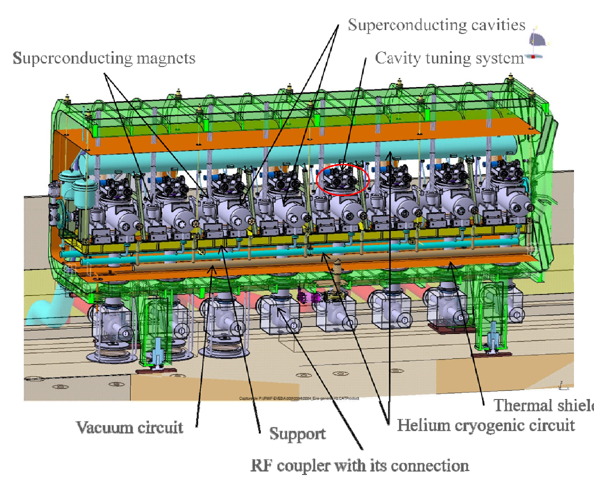


Figure 2: Cryomodule section view

### *HWR, helium vessel and tuning system design*

The superconducting HWR is made of niobium (diameter of 180mm and around 1000mm long) and it is cooled with saturated liquid helium at 4.4K, contained in a titanium vessel directly welded to the cavity flanges to minimize the interfaces. The cavity tuning range required is ± 50 kHz. A capacitive tuning system with a plunger fixed at the beam axis level has been designed: it is made of a flexible membrane of niobium-titanium with a little niobium vessel welded on it. The principle is to deform the membrane to change the distance between the vessel bottom and the beam axis which allows tuning the cavity frequency [3]. For thermal deposit and radiofrequency (RF) issues, the plunger should be superconducting and the vessel will be filled with liquid helium [4]. The plunger will be moved by an actuator constituted by a controlled motor, an infinite screw and a mechanical arm.

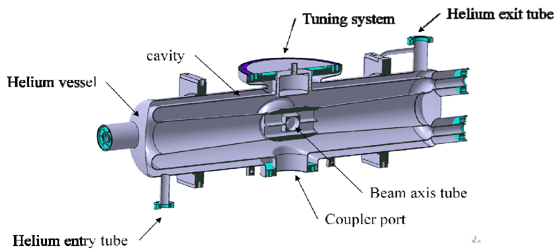


Figure 3: HWR section view

### *Solenoid Package Design*

To limit the beam losses, it was necessary to integrate between each cavity a solenoid package including a focusing superconducting solenoid magnet with a BPM. But to also respect the fringe field level required by the HWR cavities (< 20mT), it has also been added an active magnetic shielding with an anti-solenoid magnet. All these superconducting magnets are made with niobium-titanium wire and cooled down with liquid helium at 4.4K in a dedicated stainless steel helium vessel. Each solenoid package is powered by six resistive current leads cooled by helium gas [5].

### *Coupler Design*

The cavities are powered by 200 kW couplers operating in CW and made of a copper antenna around 650 mm long fixed on an insulating ceramic window [6]. The coupler is fixed vertically, under the cavity to ease the connection with the RF lines in the Rokkasho vault and therefore integrated in a space limited by the beam axis height. The antenna length is consequently a compromise between the RF optimization, the mechanical stresses on the ceramic window and the space available under the cryomodule for the integration. An appropriate coupler cooling system has been designed to maintain the cavity temperature at 4.4K: the antenna is cooled with water and the external conductor with helium gas.

### *Cryogenic circuit design*

The superconducting HWRs and solenoid packages are operating at 4.4K and each of these elements has its own saturated liquid helium bath (thus a total of 16 vessels). A double liquid helium supply has been designed as it is necessary to control the cavity cooling independently from the solenoid one. Two helium inlets manifolds have therefore been connected to the cavity vessels or to the solenoid vessels and only one phase separator collects the output helium gas at the top of the cryomodule. Some specific circuits have been added to cool down the cavity tuning systems, the current leads and the power couplers. The nominal pressure of the liquid helium circuit has been fixed at 0.12MPa and its maximum pressure will be controlled at 0.15 MPa by safety valves on the external cryogenic system. For reducing the heat losses on the cold mass, the cryomodule includes also a thermal shield cooled down at 80K by liquid nitrogen or at 60K by gas helium (solution under study).

### *Vacuum tank design*

The vacuum tank has been designed to maintain an insulating vacuum but also to support the cold mass keeping a correct alignment of the cavities and solenoids. The vacuum tank is then designed with rigid frames where the cold mass is attached. It will be fitted with a magnetic shield, a thermal shield, and several trapdoors to ease the final assembly. The feet should include jacks to align the cryomodule in the Rokkasho vault.

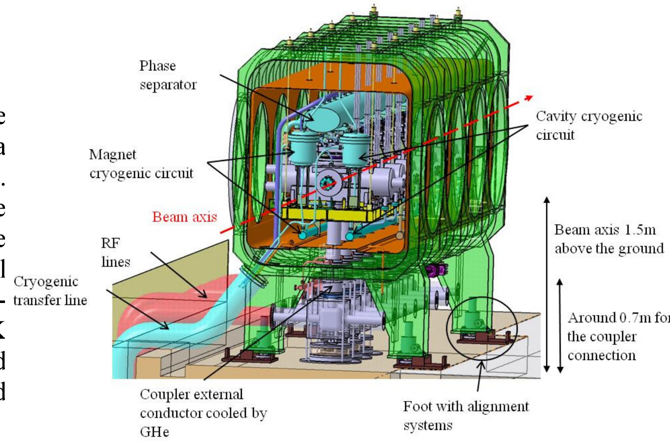


Figure 4: Cryomodule cryogenics and interfaces

## INTEGRATION AND ALIGNMENT

The beam dynamics requires aligning the cavities and the solenoid packages with an accuracy of ± 1mm around the beam axis.

### *Support and assembly*

Due to the cryomodule length, the thermal shrinking should be taken into account for the alignment. The cavities and solenoids have thus been fixed on a common specific mechanical support. It has been defined from "a double support" concept, composed of a stainless steel frame to support the element mass and an invar reference rod to control the alignment along the beam axis with some sliding attachments to manage the differential thermal deformation between the steel frame and the invar rod. This support will also be used as a base for the assembly of the cavities, solenoid packages and couplers in clean room (class 100). The end of assembly of the cold mass (including the cryogenic systems assembly) and the final alignment will be done outside the clean room. The frame will be slid inside the vacuum tank and fixed to it by several titanium rods. For the transport of the assembled cryomodule, the cold mass will be fixed with some removable tools to avoid any damage.

### *Integration in Rokkasho*

After transportation to the Rokkasho site, the cryomodule will be first controlled to check the absence of damages. The HWR vacuum level and the alignment will be controlled before the installation of the cryomodule in the vault. As the cryomodule is too heavy to be handled by the crane available in the vault, it will be slid on the floor with some removable rolling systems. After positioning, the assembly will be ended, including the connection to the other subsystems, to the cryogenic transfer line and to the RF power lines. The coupler is connected to the RF lines by a transition box and because of their differential thermal shrinking estimated around 10mm, some flexible elements have to be added on the RF lines to avoid any critical stress on the coupler ceramic window.

### *Alignment procedure*

All the accelerator subsystems will be aligned in the vault by laser tracker. The cryomodule alignment will be performed in several steps: the cavities and solenoids will first be aligned on their common support. For this purpose, these components include several mirror target supports whose positions are accurately located according to the beam axis. Next, the position of the support will be adjusted in the vacuum tank and will be precisely referenced on external mirrors targets fixed on the vacuum tank. These targets will finally be used to align the cryomodule on the beam line.

## CRYOGENIC SYSTEM DESIGN

The cryogenic plant aims to cool down the cryomodule cold mass (around 2500 kg) and to maintain the working nominal conditions of the superconducting components. It has mainly been designed to make the cryomodule operation reliable and safe more than to optimize the final thermodynamic efficiency.

### *Internal cryogenics*

The superconducting components are cooled at 4.4 K in saturated liquid helium bath at 0.12 MPa which pressure should be regulated with a minimum of variation. The cryogenic system takes into account some significant RF heat losses and also the resistive transitions due to the current leads and the couplers, connected between 4.4K and 300 K. In the final mixed mode, the thermal losses are estimated for the cryomodule around 72 W at 4.4 K (refrigeration part) and 37 l/h (liquefaction part). Two options are studied for the thermal shield cooling: with liquid nitrogen or with He gas. The first option reduces the time for the cooling down and in case of failure in the helium cryoplant, it limits the cold mass warming up and allows a quicker starting up. But this option has also drawbacks in terms of radioprotection monitoring or operation. The final option is currently under study.

### *External cryogenics*

A liquefier produces liquid helium in a large capacity dewar (2000 l) which is directly connected to the cryomodule. In this way, the cryomodule operation can continue during at least 5 hours in the case of a helium cryogenic failure. The cold box and the dewar are installed in the power supply area and are connected to the cryomodule with a vacuum insulated transfer line. The helium compressor, two large capacity buffers and the nitrogen tank will be installed in an external building. Taking into account the cryomodule heat losses and a classical margin, the helium refrigerator specification requires a 140W power at 4.4K with a liquid helium flow of 55 l/h. The helium maximum pressure is controlled at 0.15 MPa in the cryomodule by several external safety valves located outside the vault to avoid any accidental helium exhaust in the vault.

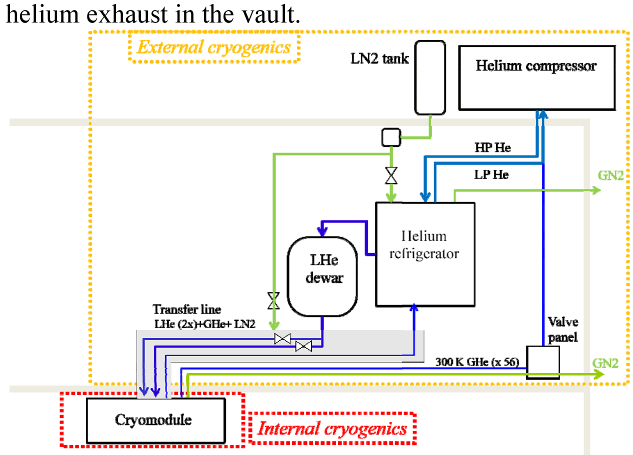


Figure 5: Principle scheme of the cryogenic systems

## CONCLUSION

The cryomodule design is still in progress, particularly the magnetic and thermal shields details and is planned to be completed for the end of the year. The cryomodule is scheduled to be assembled in 2013 and tested in CEA in Saclay before being shipped to Japan for an accelerator commissioning, which should start in June 2014.

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