

## FIRST RESULTS OF THE IFMIF/EVEDA-SaTHoRI TESTS

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### Abstract

The SaTHoRI test stand (Satellite de Tests HOrizontal des Résonateurs IFMIF) aims at characterizing a jacketed and fully dressed cavity with its RF coupler and frequency tuner. A dedicated test cryostat has been manufactured and connected to an existing horizontal test cryostat which provides the cryogenic coolant. A RF source – provided by the IFMIF/EVEDA project - has been installed and commissioned at CEA-Saclay. This paper describes the test stand and presents the first results.

### INTRODUCTION

The first phase of the IFMIF project aims at validating the technical options for the construction of an accelerator prototype, called LIPAc (Linear IFMIF Prototype Accelerator). The superconducting cryomodule components are under construction [1] and will be assembled under the responsibility of F4E (Fusion for Energy) with CEA assistance at Rokkasho Fusion Institute in Japan, where a cleanroom will be built by QST. [2, 3]. In addition to the vertical test for individual HWR qualification, the validation test of an accelerating unit (HWR [4] equipped with its tuner and power coupler [5]), which is part of a mitigation plan explained in [6], took place in a dedicated horizontal cryostat SaTHoRI before the delivery of the components for assembly. These tests will provide benchmark data for the cavity behaviour (RF, mechanical, field probe, tuner calibration...) and will allow to perform preliminary testing of some components of the SRF Linac: RF source, LCS components and instrumentation.

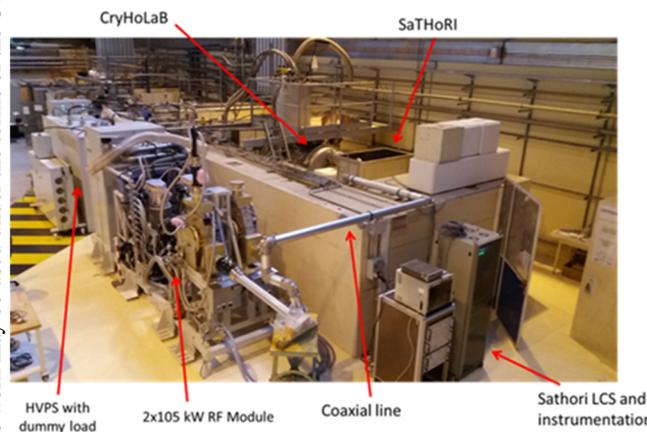


Figure 1: Test stand at CEA-Saclay.

### TEST STAND AT CEA-SACLAY

For the SaTHoRI test, a dedicated test stand has been installed at CEA-Saclay. It is made of a 175 MHz CW RF source with a coaxial line, a cryostat, a biological protection and cubicles for the local control system and instrumentation (Figure 1).

### SaTHoRI Cryostat

CEA is equipped with a horizontal cryostat called CryHoLab (Large horizontal cryostat) to test jacketed cavity equipped with tuning system and power coupler [7, 8]. Unfortunately, this cryostat was too small to receive an equipped HWR-cavity, a new cryostat called SaTHoRI has been developed. It is connected to CryHoLab in order to benefit from the already existing cryogenic distribution and the pumping system (Figure 2).

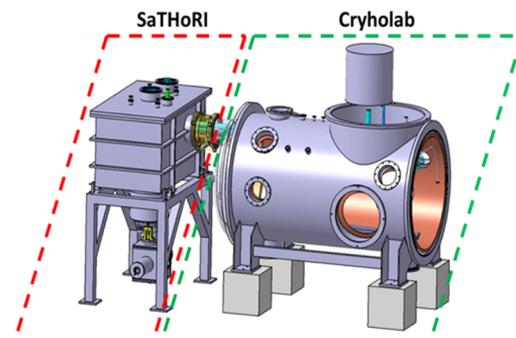


Figure 2: Principle of the SaTHoRI cryostat connected to CryHoLaB.

This new cryostat (Figure 3) mainly consists of:

- A vacuum vessel which supports the cavity / coupler assembly and insulates the cold parts from room temperature. The cavity is hung on the top lid of the vessel using four titanium alloy rods to limit the heat load on the cold parts.
- A thermal shield which limits the radiation heat flux on the cold parts. It is cooled with liquid nitrogen which is derived from the cooling circuit of the thermal shield of the CryHoLab.
- A magnetic shield made of mu-metal sheets fixed on the inner surface of the vacuum vessel to protect the cavity from the earth magnetic field. The design of this shield allows a goal of  $2 \mu\text{T}$  at the HWR surface by using 2 mm thick mu-metal sheets.

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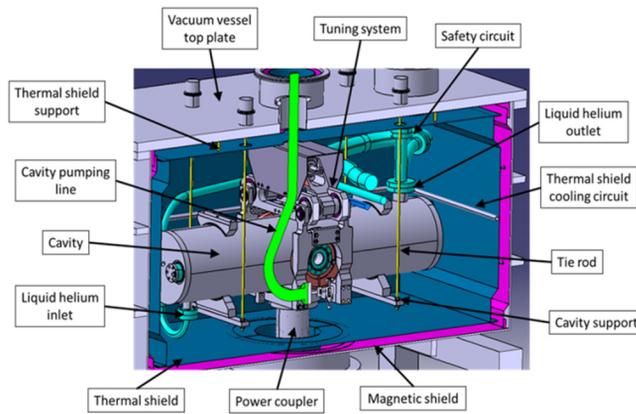


Figure 3: SaTHoRI Cryostat.

### RF Module

In order to perform some tests with RF power coupler, a RF source lent by the project has been installed in the SaTHoRI tests-stand (Figure 4). This source is constituted of 2 modules: a high voltage power supply (HVPS) and a RF module with 2 amplifiers chains. Each chain is optimized to provide up to 105 kW of RF power in CW mode [9]. The first stage of the RF chain (pre-driver) is a 400W commercial solid state amplifier. The second stage (driver) is an electron tube amplifier which integrates a tetrode in a 175 MHz cavity. It is designed to reach a power of 16 kW in CW mode. The third stage (final amplifier) built also with a tetrode is optimized to provide a RF power up to 105kW in CW mode. Each RF module is provided with several bidirectional couplers to check the RF signal at different locations of the RF chain. A high power circulator is installed at the output of the RF module with a 50kW load. All the components are cooled by demineralized water or air flow. This RF source is provided with its LLRF systems in charge to control/tune the cavities and to support fast interlock system in order to protect the cavity and its coupler. Because only 15kW is required to achieve the nominal accelerating field in the cavity, the RF source has been commissioned at 30kW at Saclay in two steps by the manufacturers with F4E: first the HVPS end of 2016, then the RF module in February 2017.



Figure 4: RF module installed at CEA-Saclay.

### SaTHoRI LCS and Instrumentation

Control/command of the SaTHoRI test bench relies on EPICS software platform. It executes high level control function as HMI (human – machine interface), archiver, cross communication with different subsystems. Low level control logic (vacuum, acquisition of temperature, cryogenic control...) and especially for the control of the tuner of the cavity are done by an S7-300 PLC from Siemens. The fast acquisition system is based on both VME boards, ADAS ICV108 and ADAS ICV178 cards with a sampling frequency of 250 kHz. This system allows acquisition of RF signals (forward and reflected powers measured by a directional coupler located between circulator and power coupler and the cavity voltage) and monitoring of multipactor and possible spark-induced light emissions close to the coupler windows. These two last measurements are also compared to adjustable threshold and then used to drive a fast interlock input of the RF module in order to stop RF in less than 20µs. Temperature sensors are also installed on the cavity and the power coupler (Figure 5). Similar instrumentation (hardware and software) will be used on the SRF-Linac at Rokkasho.

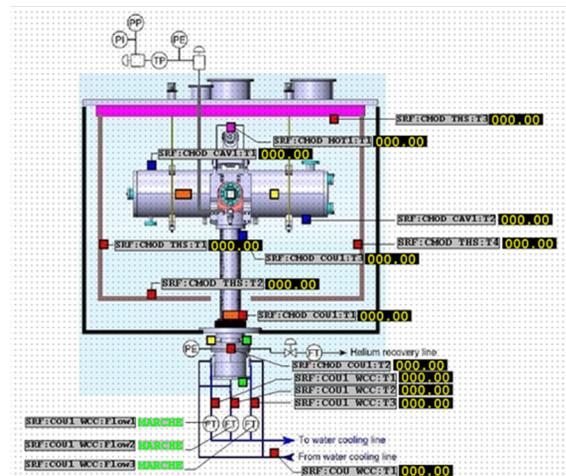


Figure 5: LCS of SaTHoRI cryostat.

### SaTHoRI TESTS

#### First Test with Critical Coupling

The first objective of the critical coupling test was to qualify the SaTHoRI cryostat with a known cavity to confirm cryogenic behaviour and magnetic shield efficiency.

The first pre-serial cavity, which has been completed and qualified in vertical cryostat [10], is selected for this first horizontal test. Therefore, thanks to the first SaTHoRI test, performances of the HWR cavity in cryomodule-like conditions, nominal orientation and equipped with the cold tuning system (Figure 6) can be compared to the previous qualification test done in vertical cryostat.

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Figure 6: Cavity installed on the top lid cryostat.

The cavity performance in SaTHoRI is presented in Figure 7. The maximum accelerating field is 7.5 MV/m. The measured  $Q_0$  at nominal field (4.5 MV/m) is  $1.5 \times 10^9$ , which is well above the specifications ( $5 \times 10^8$ ).

The cold tuning system uses a planetary gear box and a Phytion step-motor. It allows a tuning range which exceeds slightly the specified value of 50 kHz. Hysteresis measurements have been performed. A 6 Hz peak-to-peak frequency pointing error results from repeated back and forth  $\pm 15$  Hz tuning motions. For comparison, the bandwidth of the resonator equipped with its power coupler is 2.7 kHz.

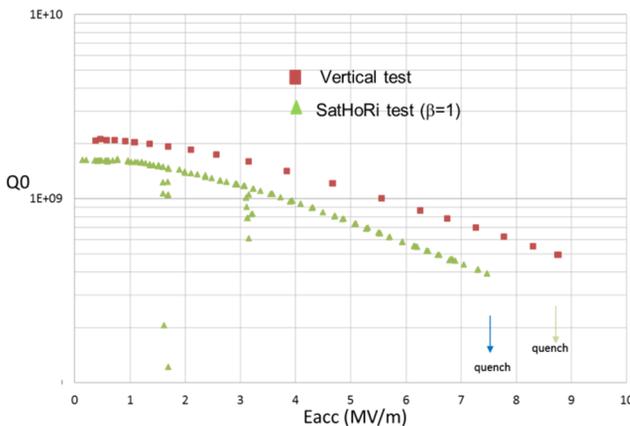


Figure 7: Horizontal test compared to vertical test.

An emergency condition can be called to cope with a sudden warmup of the cryomodule. In this case, the tuner is brought to its home position at twice the normal speed, in order to prepare for a full warmup of the module. The slew time for the full tuning range has been measured just below 1/2 hour. This is compatible with the uninterrupted power supply which will be installed for the SRF-Linac operation in Rokkasho. During the overall continuous operation of the tuner, the temperature increase of the motor is kept within a few Kelvins.



Figure 8: Cavity with its tuning system and power coupler installed on the top lid cryostat.

### Test with Power Coupler

After the first test with critical coupling, the cavity is prepared for a high power test with a IFMIF/EVEDA power coupler prototype which has been conditioned at room temperature up to 100kW in summer 2014 [11]. Then, it has been stored under nitrogen atmosphere. This assembly has also permit to validate the tooling and assembly sequence which will be used for the assembly of the whole cryomodule at Rokkasho. The cavity with its power coupler and its cold tuning system is again assembled on its cryostat (Figure 8).

The first step of this test is the warm conditioning of the coupler. An automatic procedure has been developed to control instrumentation system (mainly for the coupler protection) and to drive the RF module thanks to the LLRF. In the beginning, conditioning started at room temperature with pulse length of 20  $\mu$ s and repetition frequency of 2Hz with some hundreds of watt peak power level. The peak power level was then progressively increased up to the 25kW. At this power level, the duty cycle was increased by acting on the pulse duration or the repetition rate. During this process, some multipacting levels were encountered in the power ranges between 4 and 12 kW and 18 and 20 kW.

Once the cavity has been cooled at 4.5 K, conditioning of the coupler at low temperature is performed following a process similar to the conditioning at room temperature.

Then the cavity is tuned to the frequency of 175MHz and the cavity is fed by RF power. The nominal accelerating field of 4.5MV/m is achieved with an injected power of 14kW (Figure 9). It is worth noting that, at the administrative power limit of 20 kW defined as safe for this test without beam, the gradient reaches 5.5 MV/m.

During this test, the cold tuning system with its control has been retested and the same performances have been obtained than with the critical coupling test.

During the overall continuous operation of the coupler, tests of all coupler cooling circuits (He for the double wall tube and water for the inner conductor, the coupler window and the 'T' transition) have been also performed. The temperature of the coupler has been regulated with the LCS

of SaTHoRI thank to a heater located on the double wall tube.

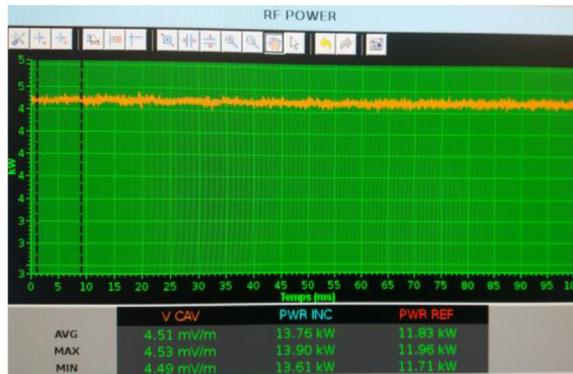


Figure 9: Signal from the pick-up probe corresponding to an average accelerating field of 4.51 MV/m measured on the HWR cavity with power coupler at  $P_i=13.8$  kW.

## CONCLUSION

The first SaTHoRI test was successful, validating the IFMIF/EVEDA superconducting accelerating unit: half wavelength cavity equipped with helium tank, with tuning system and power coupler in the final cryomodule configuration. The nominal accelerating field of 4.5MV/m was achieved with an injected power of 14kW. Thanks to these tests, the tooling, assembly procedure in clean room of a cavity with its power coupler, sequences of the control system were validated too.

## DISCLAIMER

This publication reflects the views only of several of the authors, and Fusion for Energy cannot be held responsible for any use which may be made of the information contained therein.

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