MANUFACTURING AND VALIDATION TESTS OF IFMIF LOW-BETA HWRS

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Abstract

The IFMIF accelerator aims to provide an accelerator-based D-Li neutron source to produce high intensity high energy neutron flux to test samples as possible candidate materials to a full lifetime of fusion energy reactors. A prototype of the low energy part of the accelerator is under construction at Rokkasho in Japan. It includes one cryomodule containing 8 half-wave resonators (HWR) operating at 175 MHz. The first manufactured HWR has passed low power tests at 4.2 K in vertical cryostat successfully and exceeds the specifications. 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 8 cavities which will eventually equip the cryomodule are carried out in parallel. In this paper, we focus on the HWR preparation and test results and give a status of the manufacturing activities.

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 in Japan [2, 3]. The manufacturing of a series of 8 HWRs is in progress. A pre-serial cavity has been completed and tested during the production of the subcomponents of the series. All the tuners for this total of 9 HWRs have been manufactured and delivered to Saclay. In addition to the vertical test for individual HWR qualification, the validation test of two accelerating units (HWR, tuner, power coupler) takes place in a dedicated horizontal cryostat SatHoRi before the delivery of the components for assembly.

CAVITY MANUFACTURING AND PREPARATION SEQUENCE

Due to the stiff geometry of the cavity equipped with its helium vessel (Fig. 1), the tuning system has only a limited range. It is designed to handle a tuning range of 50 kHz. The tuner has a disengagement system for coping with material differential linear expansion during cooldown and warmup phases. Only negative frequency shift are obtained with the chosen design which compresses the cavity in the beam pipe area. The limited range of the tuner stresses the importance of the initial frequency tuning which is performed mostly during manufacturing. The method here consists in trimming the length (from one torus to the opposite) of the cavity which corresponds to roughly one half wavelength of the 175 MHz radiofrequency field in vacuum. The trimming and RF measurement operations are interleaved with the welding of the four main subparts, namely the outer conductor (OC) the inner conductor (IC) and the two end torus.

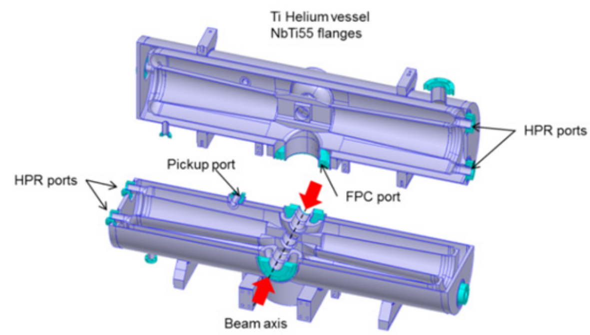

Figure 1: IFMIF HWR design.

One of the challenges is to take into account the shrinkage of three welding steps, and also to keep the beam ports aligned with the central drift tube in the IC. The current experience shows that aiming at a frequency within a range of +/- 100 kHz during manufacturing steps only (trimming and welding) is still too ambitious for this particular HWR design.

A technique of differential etching was developed in order to correct the frequency mostly between the niobium resonator body completion and the tank integration. During standard etching, the frequency is always decreasing more than foreseen. This is directly explained by the thickness measurements showing that the torus area with the highest RF magnetic field density and the HWR walls near the inlet of BCP mixture are etched preferably. In reverse, the central part of the cavity is etched at a reduced rate, and more even so the top part.

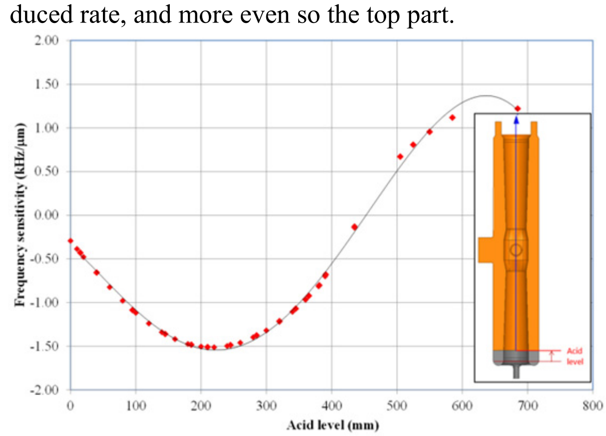

Figure 2: Frequency sensitivity to partial chemical etching.

Simulation of the local rate of change of the frequency with respect to the removed material has been investigated. Combining the local frequency sensitivity which can be obtained with the Slater theorem or 3D RF simulations and the assumption that the cavity is etched uniformly with a static (non-circulating) bath of BCP mixture up to a given height in the cavity gives the result shown on figure 2. The curve reflects the change of sign of the simulated detuning for 1 µm removal while varying the acid level. This opens the possibility of filling the HWR up to a level which either maximizes the frequency decrease or maximises the frequency increase for a given thickness of material removal. This differential etching technique can be used before the main BCP, which is more efficient for removing the damage layer, but can only decrease the frequency.

Updated Sequence

The following steps are followed after the naked Nb HWR is received from the manufacturer:

- frequency correction by differential etching,
- bulk BCP to achieve a minimum final thickness removal of 180 µm at every location in the resonator. The cavity is always etched in vertical position with circulating acid,
- High pressure rinsing (HPR) with ultra-pure water in ISO5 clean room. Each of the 4 ports is used to achieve a systematic scanning of the surface [4]. The total rinsing time with the current setup slightly exceeds 7 hours,
- optional vertical test.

The HWR is sent back to the manufacturer for:

- 24 hours 650°C heat treatment in a vacuum furnace,
- Ti helium tank welding,
- pressure test at 1.9 bar in the He vessel.

The preparation is then performed at Saclay:

- final BCP preparation and frequency correction,
- final HPR.

The last frequency correction and BCP steps should be kept as light as possible to prevent hydrogen injection in the material.

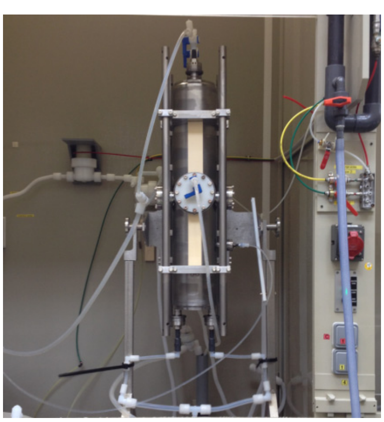

Figure 3: BCP setup.

With the current BCP setup (Fig. 3), care is taken to control the temperature of the acid mixture in the tank within less than a degree around 12°C while the acid is circulating to further mitigate this risk.

Actual Frequency Correction with BCP

The frequency correction by means of chemical etching has been fully tested. A first test was performed on one of the prototype cavities by locally etching about one 4th of the height of the HWR. This level corresponds to the maximum negative frequency change to Nb thickness removed ratio. The BCP mix is injected through the lower pair of HPR ports up to the desired level, then kept still for 25 minutes and dumped in a tank by gravity. This cycle is repeated as many times as required. On the prototype, we could confirm the efficiency of the method lowering the frequency by 40 kHz in 3 cycles.

Increasing the frequency was actually performed on the first serial HWR to recover from the -140 kHz offset from manufacturing target frequency of the bare resonator. The optimal acid level in the cavity is about 3/4 of the cavity height in this case. The number of 25 minutes cycles had to be increased to 11 to obtain the desired correction. The sequence combines 3 times 25 min in one orientation, 3 times 25 min in reverse orientation, then again 6 times 25 min in the first orientation. The average thickness removal in the process is 90 µm. Intermediate RF measurements performed after 3 and 6 cycles showed the good repeatability of the process.

PRESERIES HWR PERFORMANCE

Vertical Test Performance

A supplemental HWR has been manufactured ahead of time as a pre-series to obtain a validation of the design and most of the preparation steps and tooling. However, it was not subjected to the differential etching, but only bulk BCP with acid circulation. The vertical test preceding the heat treatment was plagued with an overall Q degradation by a factor of 10 with respect to expected values. The cavity was installed at the lowest possible position in the test Dewar, placing the lower torus in a region with 10 to 20 µT residual static magnetic field. This unfortunate choice combined with the probable presence of hydrogen injected in the niobium during BCP led to the increased surface resistance. Otherwise, good performances were obtained, Eacc reaching 8 MV/m without field emission. After being heat treated and equipped with its helium vessel, the cavity was etched in two 15 min BCP passes in opposite orientation then rinsed with HPR.

The successive vertical test was performed in the same test Dewar using an additional cryoperm shielding cap installed around the bottom of the HWR to prevent magnetic field trapping. The improved results are shown on Fig. 4. No field emission was measured showing that the rinsing method and assembly procedure is reliable. The HWR quenches at 8.7 MV/m corresponding to maximum surface fields of 96 mT and 42 MV/m for the peak surface magnetic and electric field respectively. The acceptance criteria of the project of Eacc>4.5 MV/m and Qo > 5e8 are exceeded with a comfortable margin. During this test,

ISBN 978-3-95450-182-3

the Lorentz detuning coefficient of the completed resonator was measured at -1 Hz/(MV/m)². The multipacting barriers are similar than the ones observed on the prototype cavities, with a very low field barrier at a few tens of kV/m, and a barrier starting at 1.1 MV/m which requires processing. The later multipactor discharge takes place in the torus regions, both top and bottom. This was determined during the test of the bare resonator equipped with 16 cernox sensors in critical areas by observing the correlated temperature increase.

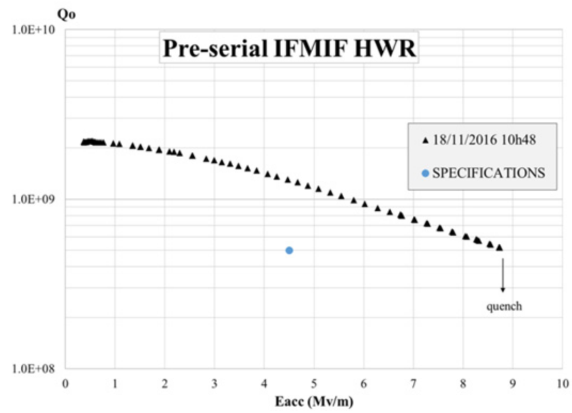

Figure 4: Pre-series HWR vertical test performance.

Horizontal Cryostat Testing with Tuner

Further testing was performed on the pre-serial HWR in the horizontal test cryostat SatHoRi. Due to tight space requirements in the vessel, the pumping port hardware of the cavity had to be exchanged in the ISO5 clean room. No additional HPWR was performed this time.

One objective was to check the SatHoRi with a known cavity to check for cryogenic behaviour, and magnetic shield efficiency. But the main objective was to test the HWR in a cryomodule-like condition, in its nominal orientation, equipped with the cold tuning system (Fig. 5).

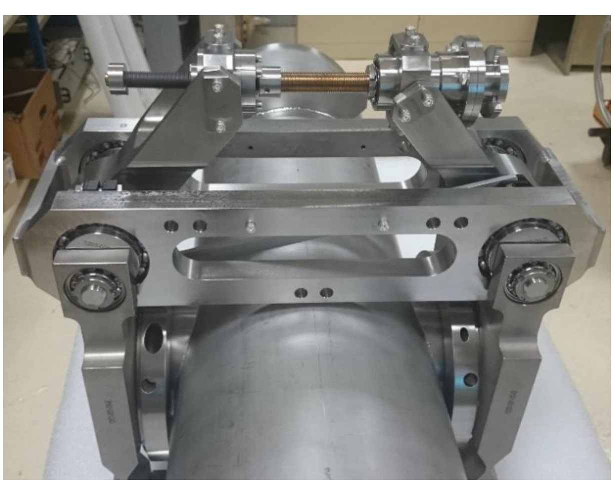

Figure 5: Tuner assembled on a mock-up HWR.

A Phytron cold motor and planetary gear box (not visible on figure 5) drives the main screw of the tuner, which converts the rotational movement into cavity compression. The tuner force is applied on the beam port flanges, through titanium flexible levers. The resulting elastic deformation of the cavity lowers its RF frequency. When the operation of the tuner is reversed up to the opposite end stop of the screw (home position), the tuner goes past a point of dis-engagement, and becomes loose. During cooldown and warmup, the tuner is always set in this loose position in order to prevent plastic deformation of the HWR.

One of the tuners has been installed on the pre-series HWR in order to check for the tuning range available. The measured tuning range exceeds 50 kHz. Hysteresis measurements have been performed on small frequency adjustments representative of what could be the operational conditions on the accelerator. A 6 Hz peak-to-peak frequency pointing error results from repeated back and forth +/-15 Hz tuning motions. When extending the tuning cycles to a +/-150 Hz range, the pointing error is kept at the same amplitude. For comparison, the resonator bandwidth is 2.7 kHz when it is equipped with its power coupler. The stepper motor is normally operated using 1/64th of steps. An emergency condition can be called to cope with a sudden warmup of the LIPAC 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 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.

The HWR performance in SatHoRi is above specifications at the operating temperature of 4.3 K. The maximum accelerating field measured during the last low power test is 7.5 MV/m.

CONCLUSION

The performance of the IFMIF half wave resonator has been demonstrated both in vertical and horizontal cryostat. All RF frequency tuning and preparation steps have been tested individually on the first HWRs with good results.

REFERENCES

[1] N. Bazin *et al.*,"Manufacturing status of the IFMIF LIPAc SRF Linac", presented at IPAC'17, Copenhagen, Denmark, May 2017, this conference.

[2] H. Dzitko *et al.*,"Technical and logistical challenges for IFMIF LIPAc cryomodules construction", in *Proc. SRF'15*, Whistler, Canada, Sep. 2015, pp. 1453-1459.

[3] J. Chambrillon *et al.*, "Assembly preparation of the IFMIF SRF cryomodule", presented at IPAC'17, Copenhagen, Denmark, May 2017, this conference.

[4] G. Devanz *et al.*, "Progress in IFMIF half wave resonators manufacturing and test preparation", in *Proc. SRF'15*, Whistler, Canada, Sep. 2015, pp. 1191-1195.