RF AND CRYOGENIC TESTS OF THE FIRST BETA 0.12 SPIRAL2 CRYOMODULE

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Abstract

The SPIRAL 2 project, installed in GANIL for Radioactive Ion Beam physics purposes requires the manufacturing of a multi beam driver. This driver is based on a superconducting LINAC [1] featuring two 88 MHz Quarter Wave Resonator (QWR) families. IPN Orsay is in charge of the study and the assembly of the 7 high energy (beta = 0.12) cryomodules. Each cryomodule is composed of two QWRs, specified to operate at 4.2 K at a nominal accelerating gradient of 6.5 MV/m. A first “qualifying” cryomodule has been manufactured and tested at the beginning of 2008 in order to validate the resonator and the cryostat design before launching the serial production of the 6 remaining cryomodules. The paper presents the main results of this test and the cryomodule design in its final version.

INTRODUCTION

A first beta = 0.12 Cryomodule was manufactured [2] in order to qualify and validate the design of its different sub components: QWR resonator, Cold Tuning System (CTS), cryogenic circuits, power coupler, alignment procedure…. For this first test the cryomodule was not in its final configuration. Only one resonator was equipped with a power coupler and a cold tuning system and the cryomodule was not shielded against Earth’s magnetic field. The cryogenic feeding valves box, the power coupler as well as the solid state 10 kW RF amplifier are also “qualifying” units of the Spiral 2 superconducting LINAC components. The different results, concerning the cryogenic, mechanical and RF performances of the cryomodule are summarized below.

CRYOGENIC PERFORMANCES

Cool Down Times

For the test, the 60 K thermal shield was cooled with Liquid Nitrogen and the 4.2 K volume with Liquid Helium at around 1.3 bars. The thermal shield was first cooled during 9 hours and reached a temperature of about 80 K. Then the cavities were cooled from the bottom. Liquid appeared on the helium buffer situated on the top of the cavities after 4 hours. However the cool down time in the temperature range from 200 K to 20 K was below 1 hour which is fast enough to prevent from Q-disease. Both cavities were cooled in parallel with only one feeding valve. We noticed a small cooling time difference in the 70K/4K range of only 15 minutes between the two cavities.

Figure 1: Spiral 2 cryomodule test stand at IPN Orsay.

Cryogenic Static Losses

Static losses (without RF) at 4 K are summarized in the Table 1. We note that for this test the cryomodule was not optimised in term of cryogenic losses and was not in the final configuration. For the cryomodule there are around 3 W more losses than expected. A part of these losses, 2 W, is explained by a lack of thermal interception sinks. For the final configuration the evaluated losses are 8.5 W.

Table 1: Static losses @ 4 K.

Component	Calculated values	Measured values
“Qualifying” CM	**10 W**	**13 W**
Valve box	5 W	12 W
Connecting box	3 W	
Single feeding line	2 W	

CAVITY ALIGNMENT

The cavity alignment is performed using fiducials. A set of 2 fiducials, fixed on the side of the resonator gives the reference of the cavity axis. There are adjusted by measuring the cavity axis before the cryomodule assembly. Windows on the cryomodule vacuum vessel allow the optical measurements of these fiducials. Each cavity is laterally maintained by four antagonist rods and vertically maintained by three rods. These rods are made from titanium alloy.

The aim of this first test was to verify the displacement of the cavity relatively to the cryomodule vacuum vessel for different operation conditions (evacuation of vacuum vessel, cool down…).

Figure 2: Cavity and cryomodule alignment.

Four vacuum vessel 4 pumping cycles where done. We measured a vertical displacement (cavities go down) of 1.4 mm with a good reproducibility (below 0.1 mm). This displacement is due to the deformation of the cryomodule top plate. A value of 1.2 mm was calculated. We measured, as expected, a no significant (inside measurement errors) lateral displacement.

After cool down at 4.2 K the cavities go up of around 1 mm for an expected value of 1.2 mm. The vertical cavity position was then easily recovered using adjusting bolts situated on the outer side of the top plate vacuum vessel. On the lateral plane we measured a displacement of around 0.7 mm for an expected value of 0.6 mm. This displacement is due to the thermal contraction of the fiducial support and the cavity helium tank. It confirms that the horizontal antagonist rods maintain the cavity axis position during cool down.

Two additional tests are planned on this cryomodule to check the reproducibility after several cool down cycles and to check a possible relative displacement inside the cavity between the central stem and the two beam ports.

COLD TUNING SYSTEM (CTS)

The tuning is performed by inserting superconducting plungers made from RRR250 niobium inside the cavity magnetic volume [3]. For the test only one cavity was equipped with one fixed plunger for static tuning and one movable plunger for static and dynamic tuning.

Figure 3: CTS with SC plunger insertion.

In the “qualification” configuration a total range of 4 mm was achieved with a tuning sensitivity of around 1 kHz/mm. A range of 8 mm is foreseen for the final version. The relation between the cavity frequency and the motors’ steps shows a sufficient linearity for few millimetres range displacements. A non negligible hysteresis of around 23 Hz (The cavity bandwidth is around 70 Hz) has been measured. Its cause is currently under study. An optimization of the frequency regulation and the reduction of the hysteresis will be performed on the next test planned before the end of the year.

CAVITY FREQUENCY STABILITY

Slow Perturbations

The pressure stability specification for the LINAC cryoplant is +/- 2 mbar, and 10 mbar/h for respectively short term and long term variations.

Frequency variations due to helium bath pressure fluctuations have been measured to -7 Hz/mbar which is acceptable taking into account the cryoplant specifications. The cold tuning system driving mechanism is installed at room temperature and the driving shaft has a heat sink at the thermal shield temperature. We have measured an important frequency shift of 60 Hz in 300 seconds caused by the thermal shield temperature variation. This variation is slow and can be compensated by the CTS regulation further more the thermal shield temperature may easily be adjusted with smaller temperature variation.

Microphonics

Microphonics measurements have been performed with a Cavity Resonance Monitor in a self oscillating loop. The excitation was done using a piezo-electric actuator situated on the cryomodule vacuum vessel top plate close to the CTS driving mechanism and one of the vertical cavity fixation rods. The excitation from 0 Hz to 450 Hz was only performed in the vertical direction. The magnitude of the excitation was not measured.

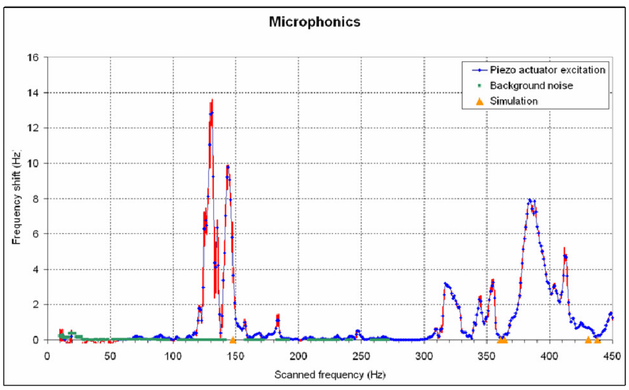

Figure 4: Microphonics measurements.

By comparison with similar measurements performed on the only cavity the mechanical modes appear to be well attenuated. This remains to be confirmed on the next test by using accelerometers to determine the excitation magnitude and performing excitation on different points of the vacuum vessel in the XYZ directions.

RF PERFORMANCES

The specified main performances [4] are Eacc = 6.5 MV/m (normalized to $\beta\lambda = 0.41$ m) and dissipated power < 10 W @ 6.5 MV/m.

Only one cavity was equipped with a power coupler. Its maximum accelerating gradient was measured to 8.5 MV/m (normalized to $\beta\lambda = 0.41$ m) and was limited by a quench. The same value was previously measured in vertical cryostat. As the cavity was not equipped with magnetic shielding the measured quality factor was low, below $1\ 10^9$ at low field instead of $8\ 10^9$ in the shielded vertical cryostat. For the next test, the cavities will be shielded by a 1.5mm thick Cryoperm® sheet fixed on the resonators' helium vessel shell and by 3 active coils fixed on the cryomodule vacuum vessel outer shell. Several multipacting barriers where present inside the resonator (the power coupler was processed) at very low field (below 100 kV/m) but were easily passed after 30 minutes processing.

VACUUM SYSTEM

The vacuum vessel is first evacuated from 1000 mbar to around $5\ 10^{-4}$ mbar using a standard Turbo-molecular pumping system with a pumping speed of 250 l/s. When the cryomodule is cold the vacuum is maintained by cryopumping. For the cavity vacuum one pumping port (coupler pumping tube c ~ 0.7 l/s) is used for maintenance purpose to evacuate or venting the cavity volume with a mobile dry Turbo-molecular pumping group and primary dry pump. Beam vacuum is maintained by the warm section (diagnostic box) pumping system. Choice is to be made between Turbo Molecular (250 l/s for N2, possibly magnetic bearing) or Ionic pump (75l/s for N2).

Due to the very small distance of the Cryomodule 300K/4K transition (95 mm) gas or vapour generated in the warm section may be a major concern for the cavity volume vacuum (H accumulation, generated by the warm section). First tests have been performed to study the effect of gas pollution (H2 and air) and interceptive beam diagnostics on the cavity performances [5].

FUTURE WORK

In the short term a new "Qualification" cryomodule test is planned for November 2008. The Cryomodule will be completely equipped with 2 power couplers, 2 movable plungers and magnetic shielding.

The first serial resonator has been tested with success ($Eacc_{max}$ = 9 MV/m with P_{diss} = 6 W at 6.54 MV/m) in August 2008. The remaining 15 resonators will be delivered and tested up to January 2010.

The cryomodule (cryostat, CTS, MLI…) call for tender is in course (design review held in April 2008). The first Cryomodule unit delivery is planned for September 2009.

The 7th unit is to be assembled and tested for the beginning of 2011.

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