SUPER-3HC CRYOMODULE: LAYOUT AND FIRST TESTS

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Abstract

Two identical cryomodules, developed at Saclay, will be assembled, tested and installed during 2002 at the 3rd generation light sources SLS and ELETTRA. Each cryomodule contains a third harmonic superconducting RF system composed by two passive 1500 MHz Nb/Cu single-cell-cavities, which were fabricated at CERN. The cryomodule components (vacuum tank, thermal shield, cold tuning system, HOM couplers) are described. Results of tests of the bare cavities in a vertical cryostat at CERN and of the complete cryomodule at CEA/Saclay are reported as well.

1 INTRODUCTION

In most of the third generation Synchrotron Light Sources, the high brightness is obtained through a reduction of the transverse beam size, leading to an enhancement of the electron density within the bunch. One consequence is the strong degradation of the beam lifetime, dominated in these sources by large-angle intrabeam (Touschek) scattering. A remedy consists in adding a voltage at the 3rd harmonic with the proper phase in order to lengthen the bunch, and thus to recover beam lifetime. Several laboratories develop such idle harmonic RF system, some using copper cavities [1,2,3], and other using superconducting cavities.

Particularly, a project based on the latter solution developed for the light sources SLS and ELETTRA, so-called SUPER-3HC [4], in the framework of collaboration between PSI, Sincrotrone Trieste and CEA/Saclay is in progress. This project consists in the study and the realisation of two cryomodules housing a Nb/Cu cavity made by CERN, and composed of two 1500 MHz cells. The specifications of this heavily damped cavity when operating at 4.5 K are:

- Fundamental frequency: F_0=1498.95 MHz
- Total maximum accelerating voltage: 1 MV
- Frequency tuning range: ±500 kHz around F_0
- Frequency regulation sensitivity: 10 Hz
- Q factor in cryomodule at Eacc=4 MV/m > 1.10^8

Moreover, to limit the beam instabilities, the requirements of HOM damping are:

- For longitudinal HOMs: 7 kΩ.GHz
- For transverse HOMs: 130 kΩ.m^{-1}

2 GENERALITIES

2.1 General layout of the cryomodule

CEA/DAPNIA made the design of the complete cryomodules (Fig.1), accordingly to the space limitations fixed by implementation on already existing SLS and ELETTRA rings. This led to a vacuum tank diameter of 800 mm and a flange-to-flange distance of 1100 mm, and explains the presence of reversed domes giving some extra-space inside the vacuum tank, what is necessary for the different components surrounding the cavity. Moreover, internal critical components, such as HOM couplers and cold tuning systems, can be easily checked through different flanges allowing easy access without dismounting the whole module.

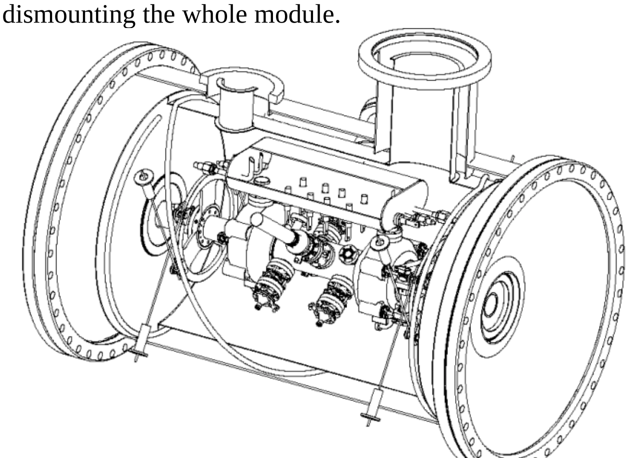

Figure 1: Schematic view of the cryomodule

Inside the vacuum tank and both sides the RF structure, two beam tubes 150 mm long (so-called ‘end-tubes’) are made out of a thin double walled stainless steel tube. Cold helium gas flow, circulating in chicane between the two walls, from 4.5 K to 300 K, limits the thermal losses at 0.2 W per tube. A 10 µm electrolytic copper coating deposited on the inner surface limits the HOM power deposition.

Moreover, in order to reduce any extra RF losses, there is no bellow all along the beam path between the external valves of the module. Thus, during cool down, the thermal shrinking of the structure makes the external tapers, on which are connected the pumps and valves, move by about 1 mm along the cavity axis. The supports of these latter components are longitudinally free to accommodate this displacement.

Several components not directly in contact with Liquid Helium (LHe) are cooled through copper breads connected to copper fingers immersed in the LHe of the reservoir located above the cavity. This reservoir, whose total volume is 17 l, insures the good separation between liquid and gas Helium as well as a sufficient reserve of LHe inside the module.

The holding system, composed by Ti rods forming an ‘X’ pattern, preserves the alignment of the cavities made at room temperature during cool down at 4.5 K.

2.2 Cold Tuning System (CTS)

Two independent CTS are implemented to tune the two cells at the wanted frequency. Each CTS is composed of a stepping motor able to work inside the insulating vacuum at low temperature, a gear box (1/100), a screw-nut system, and a double lever mechanism (1/120). Lubricating treatments were made on the surfaces of the elements submitted to friction.

The CTS is attached to the helium tank that is the mechanical reference. The CTF stiffness, measured on a test stand at room temperature, is higher than 700 kN/mm. Moreover, the calculated sensibility of 3.2 MHz/mm is in perfect agreement with the measured value. Considering the reduction ratios, one obtains a theoretical resolution of 2 Hz, lower than the 10 Hz required. This aspect has to be checked in future RF runs with a regulation loop and at low temperature.

2.3 The cavity with Helium tanks

The cavity, composed of two 1500 MHz cells linked though a large tube on which are mounted the HOM couplers, has a shape scaled from the SOLEIL cavity [5]. Its main characteristic is the continuous variation of the thickness wall from equator to iris, necessary to obtain the wanted frequency tuning range without over passing the copper elastic limit (60 MPa). With this original design, the frequency tuning range in the elastic regime is ± 600 kHz, while it is only ± 400 kHz with a 3 mm constant thickness wall. Though the fabrication of such a structure is more complicated, it was retained to insure a tuning range larger than plus or minus half the revolution frequency, and to avoid degradation of the cavities due to plastic deformations that may cause the blistering of the niobium coating.

The cavities with Helium tanks were fabricated by CERN. The cavity half-cells were machined in forged OFE copper in order to obtain the specified thickness distribution. About 200 µm in total of copper had been electrochemically and chemically removed from the surface to obtain a substrate suitable for niobium coating. Because of the small diameter of the cut off tubes (Φ61 mm), deposition of the niobium films required the development of a new magnetron cathode. Superconducting Nb films, 1.5 µm in thickness, were then successfully deposited in the new geometry and tested at 4.5K.

3 TESTS OF THE MODULE AT 4.5K

The first test at 4.5K was done at CERN in vertical cryostat on each cavity equipped with Helium tanks. The four cells (2 cells per cavity) showed very similar characteristics that are around or above specifications (Qo=2 10^8 at 4.5K and 5MV/m). Once these two cavities arrived at Saclay, they were equipped with the different couplers in clean room. At the conference time, only the first cryomodule dedicated to SLS/PSI was fully assembled and tested, and all the following results are relative to this cryomodule [7].

3.1 Cryogenic test results

For the test at Saclay of the cryomodule, we used a dewar and a single LHe transfer line. Liquid level in the tanks and the reservoir is controlled with the cold valve LCV1 and helium pressure is regulated with the other valve PCV2, located on the output Helium recovery line after a heat exchanger (Fig. 2). The heat losses have been estimated by measuring outlet gas flows.

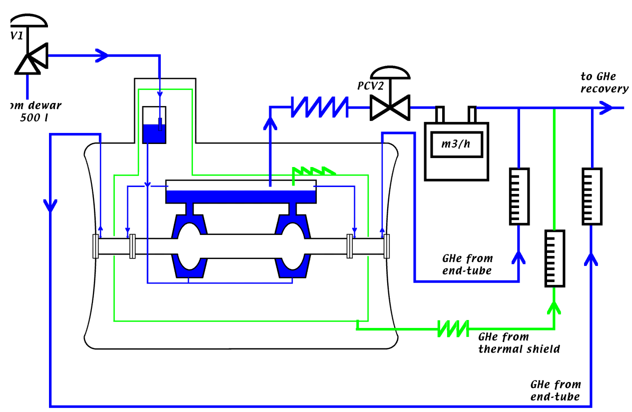

Figure 2: Scheme of the test at 4.2K at CEA/Saclay

Cool-down duration of the cold mass is around 6 hours with 0.75 g/s LHe, but the tuning system needs 6 hours more due to a smaller thermal coupling to the reservoir.

One third of the mass flow is returned out via the thermal shield in order to cool it down. The nominal flow rates of the thermal shield and the phase separator are fixed respectively to 0.065 g/s and 0.08 g/s. In these conditions, the maximum temperature on the thermal shield is 60 K and the temperature of the outlet gas is 55 K.

To maintain the LHe level to the middle of the reservoir, the total consumption of the cryomodule is 1.2 g/s. This value includes 0.027 g/s for each end-tube, 0.065 g/s for the thermal shield, and much more than 0.08 g/s for the losses of the LHe transfer line.

Static losses of cold mass were measured with LCV1 closed, the Helium pressure regulated at 1140 mbars (absolute) and the thermal shield as well as the end-tubes cooled with the above values of flow rates. Then, the static losses are found to be 10.7 watts at 4.4 K, but this value includes the static losses of the RF cables estimated at 4.5 W in the test configuration (with cables for input couplers). Notice that the value considered for the design of the cryogenic distribution inside the module was 5.3 W [7], very close to the measured value.

3.2 Cavity and coupler performances

In order to perform RF measurements, one input coupler (at critical coupling) and one pick-up probe (under coupled) are mounted on a cell. Moreover, six dedicated couplers mounted on the large tube between the cells [6] insure a heavy HOM damping. Though these couplers are designed and tuned for being weakly coupled to the fundamental mode, their effect is not totally negligible. Thus, for both cells, the Q factor loaded by the HOM couplers -as described above- has been measured versus the accelerating field (Fig. 3).

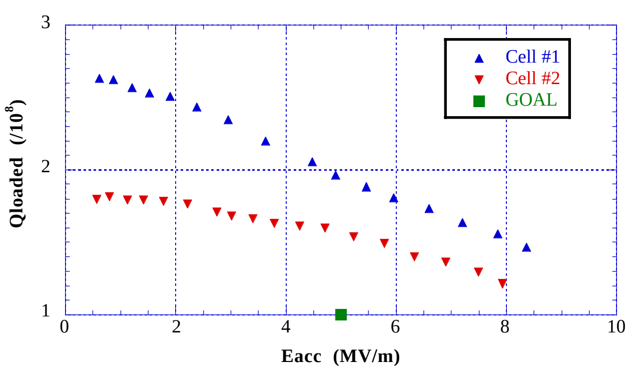

Figure 3: Q's loaded with HOM couplers vs. Eacc

The external Q of the HOM couplers especially designed for the damping of monopole modes are around 10^{10}, and those of the couplers for the dipole modes extend in the range 6.6 10^8 to 2.2 10^9. After the test at 4K, we can insure that all the couplers of the latter type can be tuned around 2 10^9, but reaching higher values would need fine tuning and two or three more cool-downs. The differences of the Qex of the couplers for each cell explain the variations between the two curves of figure 3.

One thermal test of dipole HOM couplers has also been done. Since these couplers, if well tuned on the fundamental mode, should not transfer more than 40W to a matched load, we injected this amount of RF power from the outputs of the cables connected to the couplers. The result is satisfactory, since the maximum temperature increasing at the coupler location is about 1K, insuring a stable behaviour in superconducting state. This is mainly the result of the careful cooling of the HOM cold-windows and of the cables, avoiding the heat flux generated by RF losses to reach the Niobium part of these couplers.

The damping factors of the dipole and monopole modes that can be excited by the antennas were measured. The values are in good agreement with those already measured on the 'copper model', a dedicated test bench for the optimisation of the HOM couplers [6].

In relation with the RF components, the only problem we got was due to a failure of a brazed joint between ceramic and metal of a pick-up probe. Since we got two times the same problem, we performed, after the test described above, an intensive campaign of cool-downs, at first with LN2 and then with LHe. After the last cool-down, we did not observe any leak.

4 FUTURE PLAN

After tests performed at Saclay, the first cryomodule will be delivered to SLS, in June 2002, and the second one to ELETTRA during summer 2002. Periods of shut down are scheduled for the installation on each ring, and for runs with beam at room temperature. Tests at cryogenic temperature should be made during following shutdown periods before the end of the year.

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