TESTS STATUS OF THE SPIRAL 2 LOW BETA CRYOMODULES

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Abstract

The Spiral 2 project at GANIL aims at producing exotic ion beams for Nuclear Physics. The accelerator of the primary beam is a superconducting Linac designed to provide 5 mA deuteron beams at 40 MeV. It will also allow accelerating stable ions of different Q/A values ranging from protons to Q/A=1/6 heavy ions. The accelerator should be commissioned by the end of 2011, first beam in 2012. The first tests aiming to produce exotic beams are planned one year later.

The superconducting LINAC consists of 12 low beta (0.07) quarter wave (88 MHz) superconducting (SC) cavities and 24 beta (0.14) SC cavities integrated in their cryomodule.

The status of the low beta cryomodules, supplied by the Irfu institute of CEA Saclay, is reported in this paper. The RF full power tests were performed on the qualifying cryomodule at the end of 2008 and the beginning of 2009, and the tests of the first series cavity in vertical cryostat are in course.

INTRODUCTION

The GANIL's SPIRAL 2 Project [1] aims at delivering high intensities of rare isotope beams by adopting the best production method for each respective radioactive beam.

The unstable beams will be produced by the ISOL, "Isotope Separation On-Line", method via a converter, or by direct irradiation of fissile material. On the basis of referee reports of international experts and committees, the positive evaluations by IN2P3/CNRS and DSM/CEA, GANIL, and the support of the region of Basse-Normandie, the French Minister of Research took the decision on the construction of SPIRAL 2 in May 2005.

The driver will accelerate protons (0.15 to 5 mA – 33 MeV), deuterons (0.15 to 5 mA – 40 MeV) and heavy ions (up to 1 mA, Q/A=1/3 – 14.5 MeV/u – to Q/A=1/6 – 8.5 MeV/A). It consists of high performance ECR sources, a RFQ, and the superconducting (SC) light/heavy ion linac. The driver is also asked to provide all the energies from 2 MeV/u to the maximum designed value.

The SC linac is composed of cryomodules A developed by CEA Saclay, and cryomodules B developed by IPN Orsay. Both types of cavities are equipped with the same power coupler specified for a maximum power of 40 kW CW (in travelling wave), developed in a third laboratory, LPSC Grenoble [2].

General development programs are quite similar for both cryomodules: a first qualification cryomodule has been tested before the series. These qualification cryomodules shall reach the specifications as they will be used in the machine. All the components of the series (cavities and cryomodules) are fabricated in industry. Cavities chemical treatments, HPR rinsing in clean room, assembly, and RF tests of the cavities in vertical cryostat and RF power tests of the cryomodules are performed in the respective labs.

CRYOMODULE A DESIGN SUMMARY

All cryomodules A include only one single low beta (0.07) SC cavity. This cavity is placed in a cryostat of rectangular shape. Cavity and insulation vacuum are separated. Cryogenic feeds are on the top on the module, while RF power coupler is on the bottom, connected on the removable bottom of the cavity. The cavity is shielded by a thermal copper shield cooled at 60 K, and the cavity is equipped with a mechanical tuning system.

TESTS PRESENTATION

The qualification cavity (AZ1) was tested several times in vertical cryostat (up to January 2008). Then it was assembled inside the qualification cryomodule with a prototype coupler. During assembly operations a major leak appeared. Assembly was nevertheless completed in order to validate the full assembly procedure, the various subcomponents, and in order to proceed with cryogenic and cold tests of the tuning system (August 2008). Then, in a second stage, the cryomodule was disassembled and reassembled using another power coupler. Then full RF tests were performed (December 2008, January and April 2009).

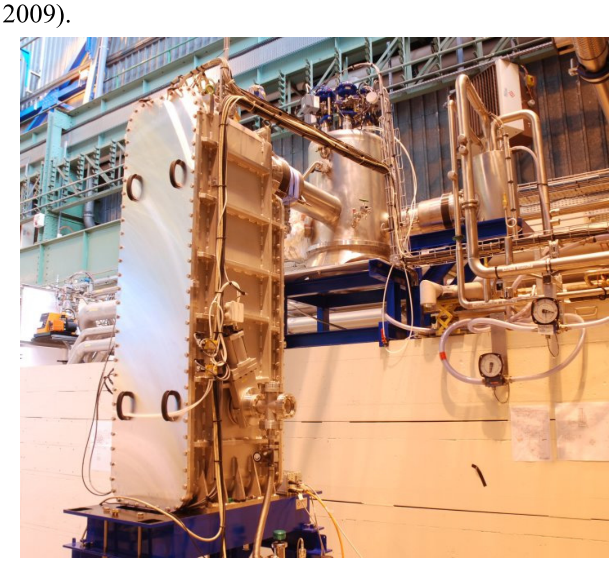

Figure 1: Cryomodule inside the test stand, connected to the valves box. RF coupler is not shown.

A specific test stand (figure 1) has been installed in Saclay in order to qualify all cryomodules A. A 10 kW amplifier, of the same type than used in the Linac, provides the RF power. The cryogenic valves box is also of the same type as used in the Linac.

VERTICAL CRYOSTAT TESTS

Vertical cryostat tests showed that the quality factor (Q_0) of the qualification cavity (AZ1) was ten times lower than the prototype cavity one (fig. 2), around 2.10^8. Otherwise, the cavity proved very stable and showed no quench up to more than 11 MV/m. Multipactor is very strong at very low field. Another (lighter) multipacting barrier is located around 1 MV/m.

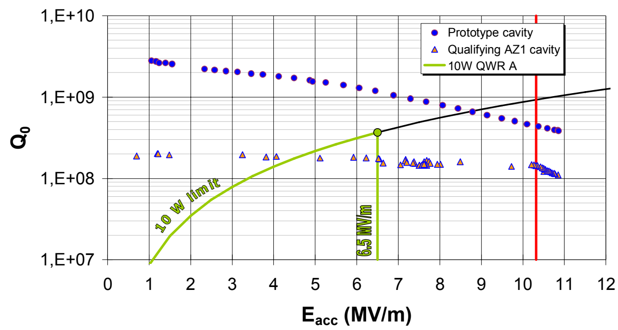

Figure 2: Q_0 vs. E_{acc} curve for the AZ1 (blue dots) and prototype (pink dots) cavities.

Several tests and analyses were conducted in order to understand the origin of the degraded Q_0. These tests allowed to locate the dissipation zone around the bottom of the cavity (but not on the removable bottom itself). The high magnetic field region, located on the torus and at the top of the stem, is not the location of the additional RF losses.

Additional investigations did not allow finding the cause of the Q_0 degradation. Bottom welds were X-rayed, RRR of the lower part of the outer conductor was measured and its chemical composition verified in situ, but none of these analyses showed any pollution.

Further investigations, now focusing on the RF contact copper vacuum seal located between the cavity and the bottom flange, are planned for this summer.

CRYOGENIC TESTS

Cooldown of the cryomodule is quite fast: 24 hours down to 100 K, then 1 more hour for the cavity to reach 4 K. The tuner is fully thermalized after only 4 days.

Static consumption of the module is comprised between 6.5 and 7.0 W (design estimations were 4 W). It has been measured by two methods: a gas flowmeter and by measuring the decreasing speed of the helium level around the cavity.

The bottom of the cavity (which is a removable niobium, U shaped plate brazed on a stainless steel flange) never reaches the SC state, with a temperature of 14 to 17 K (depending on the thermalization scheme). Further thermal simulations show that, unlike estimation, the coupler thermalization is not good enough to compensate the power coming through 300 K to 4 K (short distance). It is the main cause of the high temperature of the bottom. Thickness of the coupler's outer conductor copper plating shall also be controlled very thoroughly in order to limit losses at 4 K.

The cryogenic losses of the valves box and of the cryogenic line are much higher (around 35 W) than expected (about 15W). The helium gas return gas pipe is under sized, and causes pressure increase when additional load (cavity RF power) is added to the static loads. As a consequence the helium level was difficult to stabilize in the first step of the tests. Modifications of the return gas pipe allowed helium level stabilisation in a second step.

RF TESTS

RF power coupler has been conditioned both at room temperature (RT) and at 4 K, up to the full power of 10 kW. Moreover, power coupler had been previously conditioned on a specific stand in LPSC Grenoble. Conditioning was performed at 89 MHz, 90 MHz and 87.69 MHz (RT resonance frequency of the cavity), with a 50 Hz repetition rate and impulsion width ranging from 20 µs to CW. Multipactor barriers appeared at RT (the main ones at 4, 26, 131 and 220 W). They proved impossible to fully process, as they systematically reappeared after conditioning of the next level.

External Q factor has been measured by two means at 4 K: transmission method (using the 10 kW amplifier and a network analyser), and using the decay time factor (at low field, 5 Hz, 5% duty cycle). Measured values are $5.2\ 10^5$ and $5.4\ 10^5$ respectively, for 10 mm of penetration of the coupler's antenna inside the cavity.

RF operation was hampered by the low Q factor of the AZ1 cavity. RF losses are in the range of 35 W at 6.5 MV/m accelerating field (design accelerating gradient).

The maximum accelerating field reached was 10.3 MV/m, more than the design value required by the SPIRAL 2 project (6.5 MV/m). However duty cycle was reduced down to 5% (5 Hz) in order limit the thermal load that could destabilize the cryogenic system.

Continuous mode could be maintained at a gradient of 6.5MV/m for about 40mn before a helium level instability due to over consumption stopped the RF power.

TUNING SYSTEM TESTS

The tuning system is not screwed on the cavity on both sides: therefore, it can be used to squeeze the cavity but not to pull it. In order to change the frequency in both direction (and to avoid any floating point) it is planned to place the neutral point around the middle of the tuning range (25 kHz theoretical), leading to +/-12 kHz of range.

For the first test, the tuning system was initially put just in contact with the cavity (at the extremity of its range), and not bolted to it. After a single thermal cycle of cooling down and warming up, the resonance frequency of the cavity was permanently lowered by 5 kHz. This can be explained by the differential shrinkage between niobium (of the cavity) and stainless steel (of the tuning system) (see figure 3).

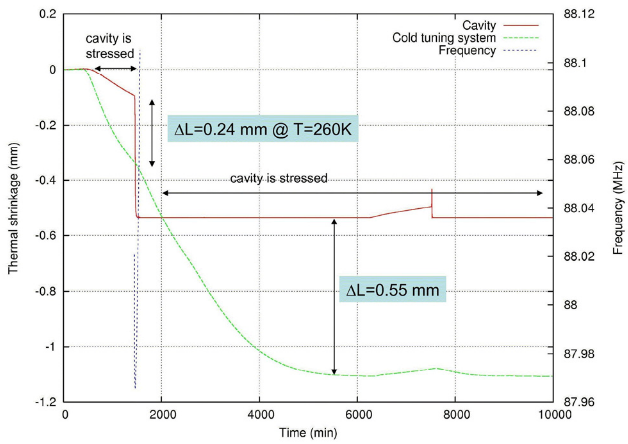

Figure 3: Differential shrinkage of the cavity and tuning system during cooldown.

During the nitrogen cooldown phase (0 to 1500 min on fig. 3) shrinkage of the tuning system is three times higher than the one of the cavity. Therefore the cavity in constrained by the tuning system. During the helium cooldown phase (around 1500 min on fig. 3) shrinkage of the cavity is higher than the one of the tuning system: therefore the cavity is free. Then while the tuning system temperature cools down slowly its shrinkage becomes once more higher than the one of the cavity, now stabilized at 4 K (between 2000 and 6000 min on fig 3): once more the cavity is constrained It shall be remembered that the niobium elastic limit is 40 MPa at RT and around 400 MPa at 4 K. Therefore, while the deformations caused by the differential shrinkage at 4 K remain purely in the elastic domain, the cavity is plastically deformed during the nitrogen cooldown phase.

Thus, before any cooldown, the tuning system shall be placed some 1.3 mm away from the cavity. This was performed during the next cooldowns and no more permanent frequency shifts were observed.

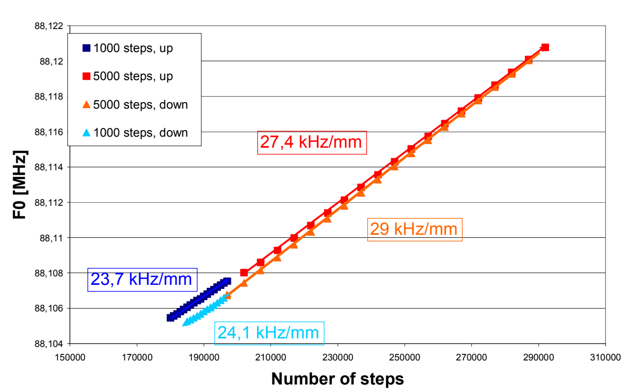

Figure 4: Tuning system sensitivity showing slight hysteresis (cavity frequency vs. number of motor steps).

Sensitivity of the tuning system is as expected. Full excursion of the tuning system and way back show a slight hysteresis of 1 kHz (fig. 4). This hysteresis has disappeared after 2 cycles. Frequency linearity downward is slightly better than upward (in terms of frequency). One can explain it by the fact that the tuner contact on the cavity is better when the force applied is stronger.

CAVITY ALIGNMENT

Displacements of the cavity inside the cryomodule during pumping, cooldown and warmup operations have been measured by two means. Firstly, the beam port flanges of the cavity have been equipped with special copper vacuum seals. These seals were machined with lug-shaped sights (three per seal), which allowed to check the cavity movements by optical means in all dimensions. Secondly, a displacement sensor (Swema) qualified for cryogenic temperatures operation has been mounted on the bottom flange and the cavity. The moveable part of the captor has been tied on the cryostat top and bottom walls with an Invar string in order to check vertical displacement of the cavity.

Pumping shows a vertical displacement of the beam axis lower than 0.1 mm.

Cooldown show a vertical displacement of 1.13 mm by optical method, and of 1.07 mm by the displacement captor. No horizontal displacement is measured.

Computations showed a vertical displacement of 1.11 mm upward during cooldown. Alignment tolerances of the beam axis are +/-1 mm.

FUTURE ACTIVITIES

The next cavity (called AZ2) is presently being tested in vertical cryostat. Its helium tank has not been welded in order to ease further tests in case of failure. After qualification of this cavity’s performances, helium tank shall be welded and final acceptance tests in vertical cryostat performed. The third cavity (AS3) delivery, also without helium tank, is scheduled for the end of May. It comes from a second manufacturer.

The qualification cryomodule and the AZ1 cavity shall now be disassembled. AZ1 cavity shall be tuned to the proper frequency. Further tests are scheduled in order to identify the origin of the low Q_0. The qualification cryomodule shall be upgraded to the series standard, mainly as far as the magnetic shield is concerned. Magnetic shield will consist of a 1-mm thick foil of Mumetall® placed on the inner, RT face of the cryostat. Integration and magnetic tests of the first magnetic shield are scheduled for October, 2009.

The series cryomodule shall be ordered very soon. They shall be delivered starting from March, 2010.

REFERENCES

[1] T. Junquera, P. Bertrand, R. Ferdinand, M. Jacquemet, "The high intensity superconducting Linac for the SPIRAL 2 project at GANIL", proc LINAC 2006, Knoxville, USA, p 142-144.

[2] Y. Gómez Martínez et al, "Theorical study and experimental result of the RF coupler prototypes of Spiral2", EPAC 06, Edinburgh, June 2006.