Status of the SPIRAL 2 Superconducting LINAC

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Abstract

SPIRAL2 is a radioactive beams facility, composed of a superconducting linac driver, delivering deuterons with an energy up to 40 MeV (up to 5 mA) and heavy ions with an energy up to 14.5 MeV/u (up to 1 mA). The superconducting linac is composed of two families of quarter wave resonators: type A (optimized for beta=0.07, 1 per cryomodule) and B (beta=0.12, 2 per cryomodule). The accelerator is scheduled to be commissioned from mid-2011 onwards. The project is therefore in production phase. This paper summarizes the latest results and the status of the superconducting linac. All 16 type B cavities have been tested. Cryomodules from both families are presently being assembled in series. Installation of the cryomodules in the new building in GANIL shall begin in August 2011.

INTRODUCTION

The GANIL's SPIRAL2 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 SPIRAL2 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) 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 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

The qualification cryomodule has first been tested between December 2008 and April 2009 [3]. Recently, after full disassembly, the qualification cavity (AZ-1) has been tuned, HP rinsed, and reassembled inside its cryomodule. Tests of this module have begun in April 2010 and are still ongoing.

In the meantime, the first two series cavities (AZ-2 and AS-3) have been received, one from each manufacturer.

Latest Developments

Early tests of the AZ-1 cavity showed a very poor Q_0 (10 times lower than expected) [3]. The degradation of the Q_0 was caused by the dual purpose seal (RF and vacuum) linking the cavity to its bottom cap. This failure was demonstrated by replacing these seals with indium ones (see Fig. 1) during vertical cryostat tests. From now on these copper seals are replaced by Helicoflex© seals.

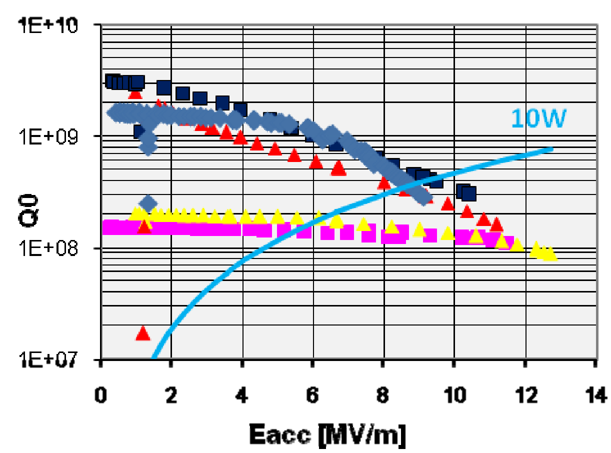

Figure 1: Vertical tests results of the three A-type cavities. Two bottom curves (yellow and pink) are cavities with a copper, dual purpose seal. All other curves are the three cavities with an indium seal. The blue dot curve show a cavity with an indium seal and copper bottom cap.

Tests in the qualification cryomodule proved that it was very difficult to maintain the niobium bottom cap below 10K, mainly due to the thermal losses coming from the coupler. Therefore niobium caps have been replaced by high RRR copper caps. Computations show that additional RF losses would be 1 W in a bottom cap made of RRR=70 copper. The AZ-1 cavity has been tested with such a copper cap in vertical cryostat; results proved satisfactory (see Fig. 1).

Fine tuning of the cavities is performed chemically. Removing thickness preferentially at the top of the cavity (magnetic torus) lowers the frequency, whereas removing niobium preferentially at the bottom of the cavity (around the beam tubes) raises the frequency.

A new magnetic shield has been developed and manufactured. It is made of 1-mm thick Mumetall© plates assembled on the inside wall of the vacuum chamber. Its efficiency has been measured and is better than 50 around the cavity.

Ongoing Activities

The qualification cryomodule is presently being tested in Saclay. Cavity inside this cryomodule is the AZ-1 one, with a copper bottom cap fitted with a Helicoflex© seal. Preliminary results showed that alignment of the cavity inside the cryostat is unsatisfactory and shall be enhanced. We still have the possible adjustment of moving the whole cryomodule on axis at the price of a reduction of the apparent beam aperture. The cryogenic system shall also be slightly modified to limit apparent cryogenic losses and to stabilize the helium bath level; the real cryomodule consumption has still to be measured.

Coupler conditioning was performed easily both at 300 K and at 4 K. Conditioning procedure includes both pulsed and cw modes; pulsed modes are operated at 50Hz. Usual multipacting barriers have been observed at low power level (around 20 and 150 W of peak input power).

Figure 2: Series cavities just before tuning operation in the manufacturer premises.

A prototype LLRF system foreseen for the accelerator has been successfully tested. Despite high helium consumption (and with helium bath pressure fluctuations of ±2 mbar), the LLRF and tuning systems managed to maintain the phase shift within ±0.1° with respect to the RF pilot (specifications: ±0.5°), and the field amplitude in the cavity within ±0.12% (specifications: 1%).

The tuning system performed satisfactorily, until it blocked after 12,000 motor turns. The harmonic drive gear box, operating under vacuum and at 4 K, and the CuBe screw are under suspicion.

Further tests are being performed and full analysis of the results still has to be made.Series cavities fabrication is ongoing smoothly and according to schedule (see Fig. 2). All cavities are presently in the tuning stage. Tuning is performed by adjusting the cavity height: last two welds are the ones linking the stem to the top torus and the top torus to the cavity body respectively (as seen on Fig. 2). By cutting the stem and the cavity body to the proper length, it is possible to adjust the resonance frequency of the cavity with a sensitivity of 83 kHz/mm. This system has been qualified by both manufacturers on AZ-2 and AS-3 cavities. Manufacturers are required to deliver all cavities with a frequency precision of ±25 kHz.

Foreseen Activities and Schedule

All elements of the first series cryomodule have been delivered in Saclay. This cryomodule shall be assembled during the summer 2010 with the AZ-2 cavity. This cavity has already been tuned but shall be finally qualified in vertical cryostat before being put in the cryomodule. Tests of this cryomodule are scheduled for September 2010.

All series cavities shall be delivered in Saclay between June and September 2010. Upon reception they will be tuned chemically and individually tested in vertical cryostat for final acceptance. It is scheduled that all cavities will be qualified before the end of 2010. It will be the first final cryomodule.

In parallel, remaining cryomodules components, presently under fabrication, will be delivered before the end of the year in two or three batches. Assembly of the 10 remaining cryomodules shall begin before the end of 2010.

Final delivery of the last tested cryomodule to GANIL is foreseen for the first quarter of 2011.

CRYOMODULE B

Cavities Tests

The production of the 16 beta 0.12 cavities was achieved in November 2009 (see Fig. 3). All cavities have already been tested once in vertical cryostat at 4.5 K (see Fig. 4). There all satisfy the SPIRAL2 linac requirements (less than 10 W of dissipated power at 6.5 MV/m).

Figure 3: Family picture of some B cavities.

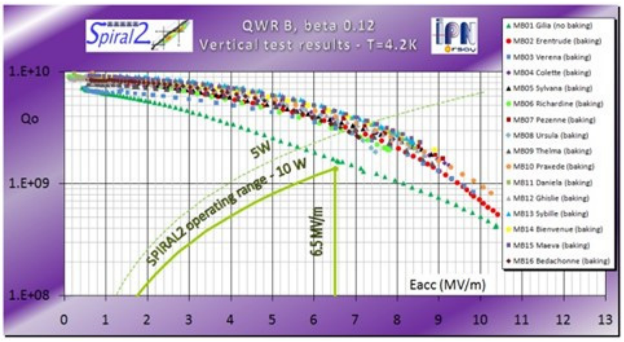

Figure 4: Vertical tests results for all 16 type B cavities.

All cavities have been BCP etched. In order to get a more homogenous etching rate, the chemical treatment is done in two phases (2x2h, the cavity is turned upside down after the first phase) and the cavity is "cooled down" by circulating water within its helium vessel during the process. We ended up with a sensitivity of +0.14 kHz/min, with a very good reproducibility (±0.02 kHz/min) for more than 15 chemical processes.

The dissipated power at 6.5 MV/m has been divided by a factor of two (mean value of 4 W instead of 8 W), thanks to the baking of each cavity at 110°C for 48 h. The baking is done in clean room after HPR. Hot air is directly blown in the stem and goes out by one of the CF16 flanges of the helium vessel (see Fig. 5). A heater ensures baking of the bottom end of the cavity, which is not in contact with the helium vessel. The cavity is wrapped in a foil blanket during the process.

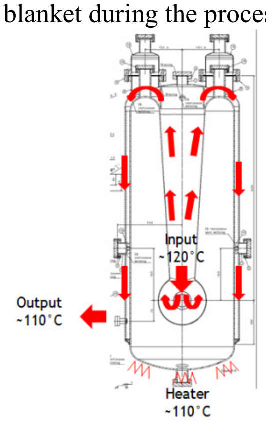

Figure 5: Sketch of the hot air flux for cavity baking.

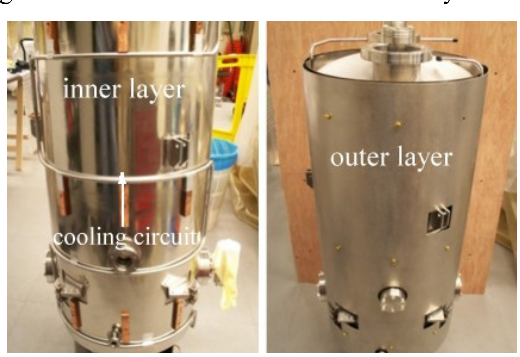

Figure 6: MB14 cavity equipped with its dual-layer magnetic shield.

Magnetic Shield

The two first magnetic shields have been delivered in April 2010. The magnetic shield is composed of two layers of 1-mm thick Cryoperm© and a stainless steel cooling circuit. The goal is to cool-down (ideally below 20 K) the magnetic shield before the normal to SC cavity transition, to ensure that the shielding efficiency is optimal at the time of the transition. One shield has been successfully tested with the MB14 cavity in vertical cryostat (see Fig. 6). The temperature of the shield was around 30 K before the cavity transition.

Cryomodules Fabrication

In addition to the prototype cryomodule which will be installed in the linac tunnel thanks to very good performances [4], the production of the 6 other cryomodules B components is going to be ended in June 2010. Three cryomodules have already been delivered to IPN Orsay; the last one will be delivered in October 2010.

The assembly of the first cryomodule has begun. This cryomodule should be tested in September 2010. Each cryomodule will be individually tested at IPN Orsay, one every 2 months, before shipment to GANIL.

RF POWER COUPLERS

21 of the 30 power couplers have been received by the LPSC laboratory in Grenoble.

The ceramic window of two first couplers broke down during conditioning, seemingly because TiN coating was too thick. A thinner on (1nm) was tested with success by gave higher multipacting. Therefore TiN coating was abandoned for the remaining couplers.

Of the remaining 19 delivered couplers, 6 have been fully tested and conditioned. No incident occurred and couplers are being delivered to the cryomodules assembly teams in Saclay and Orsay according to schedule.

Following the cryomodule A and B tests next autumn 2010, the method to keep the temperature of the ceramic window above 14°C (to avoid freezing) will be chosen. Two options are still being considered: either a self regulated heater will be placed on the outer conductor as close as possible to the ceramic, or filtered air will be flown in a channel around the ceramic.

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