STATUS OF THE ALPI LOW-BETA SECTION UPGRADE

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Abstract

The low-beta section of the ALPI linac at Laboratori Nazionali di Legnaro is being upgraded in order to double its energy gain from about 10 MV to 20 MV. This upgrade, performed with a rather limited investment in the background of the standard accelerator activities, is based on the replacement of some rf system components and minor modifications to the cryostats. The cavities, working at 80 MHz, require a 3 dB rf bandwidth of 15 Hz (obtained by means of strong overcoupling) to be locked in the presence of the large Helium pressure fluctuations of ALPI. Their average gradient, although exceeding 6 MV/m at the nominal 7 W power, is presently kept around 3 MV/m during operation, limited by the maximum available rf power in the linac. The ongoing upgrade requires the modification of all low-beta cryomodules to allow new, liquid Nitrogen cooled rf couplers and new, 1 kW amplifiers. A fully equipped prototype cryostat with four, beta=0.047 QWRs has been constructed and tested on line, and operated at 6 MV/m reaching or exceeding all design goals.

INTRODUCTION

The superconducting heavy-ion linac ALPI-PIAVE includes 80 MHz β=0.047 and 0.055 Quarter-Wave Resonators (QWRs) with the originally specified accelerating gradient of 3 MV/m with 7 W rf power. In order to operate reliably the cavities in the presence of environmental noise and Helium pressure fluctuations, these resonators require an rf bandwidth of about ±15 Hz, that is obtained by overcoupling the cavity and sending to the cavity approximately 50 W forward power from amplifiers. These numbers drove the design of the original rf system. Most of these cavities, however, are capable of more than twice the specified gradient at 7W and can thus deliver a twice larger acceleration to the beam, provided that the necessary rf bandwidth is maintained. This would require operating at 6 MV/m with 200 W forward power. To reach this goal and double the acceleration capability of the linac low-β section from about 10 to about 20 MeV/q in a rather inexpensive way, we decided to upgrade the old rf system [1][2] using a design concept that was successfully developed at TRIUMF [3]. This requires the replacement of the old 150 W amplifiers with 1 kW units and the replacement of all existing 80 MHz RF couplers with new ones cooled with liquid Nitrogen and able to sustain 200 W. We could take advantage of an existing, but empty cryostat that was equipped with 4 new resonators, upgraded and used as the prototype for all low-β ones. This extra cryostat allowed us to reduce the new specifications for the cavities operation gradient from 6 to 5 MV/m in order to reduce the liquid He consumption, which is a critical issue in ALPI. The upgrade main phases are the following:

1. replacement of all RF amplifiers.
2. construction, installation and testing of the first upgraded cryostat and of the liquid Nitrogen distribution system.
3. upgrade of the 5 remaining low-β cryostats with the inclusion of cooled couplers.

This upgrade was originally conceived as a 3 years program, to be held in parallel with accelerator operation. The first half of the program, including phase 1), cavity construction and testing and successful R&D of new components (Fig. 1), was completed on time. Unfortunately, due to changes in the laboratory plans, the work on the prototype cryostat had a long stop and was shifted to low priority till the end 2009.

Figure 1: The low-β cavities in the prototype cryostat.

UPGRADE STATUS

The program has now restarted. Phase 2) has now been completed, the prototype cryostat was successfully tested on line in spring 2010 and now the last phase was entered.

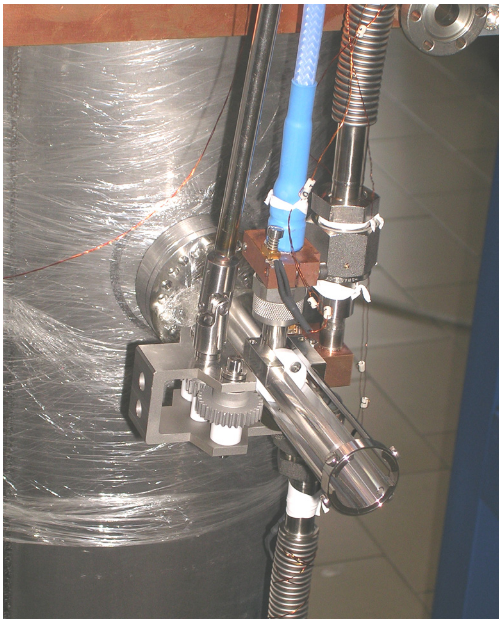

Figure 2: The new cooled coupler.

RF System

All low-β cavities have been equipped with 1 KW solid-state RF amplifiers able to work in cw mode with up to 500 W in full reflection, and more than 1 kW in pulsed mode. Even when resonators are operated in the old configuration, with 50 W forward power and E_a=3 MV/m, this extra rf power gives a large margin in managing transients caused by large pressure changes in the Helium delivery system, and cavities can be maintained in a phase- and amplitude-locked state for the time required to the mechanical tuner to recover the right frequency.

Quarter-wave Resonators

Four β=0.047 cavities with a modified design have been constructed. A new flange design allows removal and replacement of the mechanical damper without the necessity of opening the indium seal. The cavities have been installed in the protorype cryostat and equipped with new RF couplers (Fig. 2), cooled with liquid Nitrogen, that can manage more than to 250 W in full reflection and allow operation up to 6 MV/m with about ±15 Hz rf bandwidth.

New slotted tuning plates, giving a tuning range close to 30 KHz, were used (only 10 KHz could be provided by the old Cu-Nb ones). Aluminum covers allow protection against dust contamination of the cavities through the slots during cryostat assembly. Couplers and tuners characteristics are described in Ref. [2].

Cryostat Upgrade

The upgraded low-β cryostat prototype has a new liquid nitrogen line, made of flexible stainless steel bellows, bringing the coolant to the adjustable rf couplers connected in series. The cryostat is connected to the liquid Nitrogen distribution system via bayonet connectors for easy removal. The flow rate can be regulated, and typical operation pressure at the cryostat input is 150 mbar, giving a total flow below 10 L/h. Rf cables are cooled by radiation and by contact with the rf coupler on one end, and with the rf feedthrough on the top of the cryostat on the other end. An aluminum shield, linked to the 60 K cryostat shield cooled by helium gas, protects the helium reservoir from the heat radiated by the RF cables (Fig. 3). The shield, all the tubes and joints can be easily dismantled during cryostat and cavities maintenance. In addition to the standard ones in cavities and cryostat, extra temperature sensors have been mounted on couplers, rf lines and liquid nitrogen line for temperature monitoring.

We have replaced the old, Cu plated stainless steel coaxial rf lines, prone to fatal failure when rf power flow exceeded 150 W, with SUCOFLEX 106 rf cables connecting directly rf couplers and vacuum rf feedthrough on the cryostat top plate. Thermal isolation is now provided by the stainless steel, thin wall rf coupler holder.

The prototype cryostat was assembled and installed in ALPI in 2009. In the absence of liquid Nitrogen cooling, it was used for about 1 year as a standard cryostat for beam acceleration with the old operation parameters of E_a=3 MV/m and P_f=50 W.

Figure 3: View of the flexible liquid Nitrogen line for rf coupler cooling and the Aluminum thermal shield.

ON LINE TESTING

Operation in the upgraded configuration, with E_a=5 MV/m and P_f=200 W could be tested only in spring 2010, when the liquid Nitrogen distribution system could be finally put in operation. To validate the prototype cryostat for operation in the new specified conditions, a set of tests have been performed during a total time of about 4 weeks.

Resonators rf Test

All cavities exceeded the specifications and could be locked at 6 MV/m with less than 7 W rf power dissipation each. Due to time constraints, Rf and Helium conditioning were applied up to the point required for reliable operation at that gradient, which is the maximum that we think we could use in our linac for beam acceleration.

Liquid Helium Consumption at 4.2 K

Thermal load to liquid Helium of the whole cryostat and of different components have been obtained by measuring the liquid Helium consumption in different operating configurations and after cryostat thermalization. Results are shown in Table 1.

Table 1: 4.2 K Thermal Load in the Prototype Cryostat

Test type	measured	specified
Static*	~5	≤5
E_a=3 MV/m, P_{for}=50 W*	~11	≤35
E_a=5 MV/m, P_{for}=200 W**	~17	≤35
E_a=6 MV/m, P_{for}=200 W**	~23	≤35
4 couplers, P_{for}=200 W**	~5	≤4

* without liquid N cooling; ** with liquid N cooling.

The cryostat Helium consumption in operation has largely exceeded the design requirements. At 5 MV/m, the new design operation gradient, the power load was only half the maximum specified one. Operation could be done even at 6 MV/m keeping well below the maximum allowed limit. Static load with no cooling was also as expected and similar to the one of standard cryostats.

The thermal load of the all four couplers at 200 W seems to slightly exceed the design limits giving a small extra load of 1 W. This result, however, is comparable to the measurement precision and difficult to evaluate.

Temperature Distributions in Steady State

An important test was the temperature distribution inside the cryostat in steady state, especially the one of rf cables and Aluminum shield which are cooled only indirectly by mechanical contact and by heat radiation. The main risk to be avoided was overheating of rf connectors and vacuum feedthroughs, which could lead to possible vacuum leaks and serious damages to the rf lines. Tests were held for periods varying from 24 hours to 1 week of continuous operation. The system could reach thermal stability after about 6 hours. The steady state temperatures are shown in Table 2.

No temperature exceeded values that could be considered as dangerous ones, being far below the specified operation temperature of cables, connectors and feedthroughs. The highest temperature was reached in one rf coupler during operation in the old standard configuration without LN cooling; this high value, however, did not result in a significant thermal load.

Table 2: Steady State Temperatures in the Cryostat

P_{for} (W)	50	200	250
E_a (MV/m)	3	5	5
LN cooling	No	Yes	Yes
T coupler (K)	330	89	89
T cable-coupler connector (K)	278	167	166
T cable-middle (K)	234	279	296
T cable-feedthrough connector (K)	248	287	305
T aluminum shield (K)	55	77	60

Long Term Tests in the New Operating Conditions

The final part of the test was devoted to the demonstration of operation capability at 5 MV/m. The cryostat was locked for 5 days in this operating conditions. Although the run was affected by numerous Helium pressure instabilities from the cryogenic system, and by the need of replacing one failing rf amplifier., reliable long-term locking was obtained after optimization of the operation parameters.

To demonstrate operation with comfortable safety margin, cavities have been locked also at 6 MV/m for shorter periods. Also in this case phase and amplitude locking was reliable and no unlock was observed in steady state conditions. The test was finally concluded at the restart of the normal linac operation.

CONCLUSIONS

The ALPI-PIAVE low-β upgrade has restarted and the prototype cryostat was successfully tested on-line and put in operation. The next stage of the project will consist of upgrading the 5 remaining low-β cryostats. This operation should be performed with minimum interference with the standard linac operation and, according to the updated laboratory planning, completed within 2011.

ACKNOWLEDGMENTS

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