

HARDWARE COMMISSIONING OF THE REFURBISHED ALPI LINAC AT INFN-LNL TO SERVE AS SPES EXOTIC BEAM ACCELERATOR

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Abstract

The ALPI linac at INFN-LNL was substantially refurbished in 2018, especially in view of its use as secondary accelerator for exotic species in the framework of the SPES project. In particular: 10 magnetic triplets were replaced with higher gradient ones; two cryomodules with quarter wave resonator were moved from the PIAVE injector to ALPI, so as to make them available both for exotic and stable beams; the cryogenic plant was renovated; the whole linac, its injector and its beam lines were eventually realigned via LASER tracking (LT). The expected outcome of the refurbishment project is a larger beam transmission (crucial for the efficient transport of the unavoidably low current exotic beams) and improved overall reliability so as to further extend the lifetime of an already 25 years old machine. The hardware commissioning of this new configuration will be reported.

INTRODUCTION

In April 2018, beam operation at the Tandem-ALPI-PIAVE accelerator complex in Legnaro was suspended, so as to concentrate the resulting manpower effort on the refurbishment of the ALPI linac in view of its exploitation within the SPES facility. The SPES project [1] regards a second-generation ISOL-type facility for exotic beams, generated through the interaction of a 40 MeV 200 uA proton beam from a commercial cyclotron with a UC_x target, linked to Surface Ionization, Plasma and LASER Ion Sources (SIS, PIS; LIS). The extracted beam, with charge state 1+, will be either sent to low energy experimental stations or accelerated with ALPI. For both cases, a high-resolution mass separation stage ($M/\Delta M \sim 20000$), preceded by an RFQ beam cooling device, will be used if required. Prior to the acceleration stage, the beam charge will be boosted in an ECR-type charge breeder (CB), purified from the contaminants introduced by the CB itself, driven to a normal conducting CW 80 MHz RFQ and then to the superconducting linac ALPI through a MEBT line matching the linac injection parameters via two 80 MHz QWR room temperature bunchers and quadrupole triplets. At present, the cyclotron has been commissioned to the design energy (70 MeV) and current (500 uA), the target-ion-source station is available off-line (while infrastructure work on both the target bunker and related laboratories is being carried out) and the CB injector ADIGE is in construction [2]. In the meantime, the ALPI layout (Fig.1) has been modified and refurbished, by displacing two QWR cryostats from

PIAVE and increasing by 50% the gradient of 10 quadrupole triplets.

In their new positions (CR01 and CR02) the displaced cryostats will be available for acceleration both from the old stable beam injector PIAVE [3] and from the RFQ of the ADIGE exotic beam injector. Increase of the field gradient in 10 triplets is expected to improve beam transmission along the linac, at the primary advantage of very low current (sub-nA) exotic beams and of stable beams too. These refurbishments, implemented in the period April 2018 – March 2019, came together with the reconfiguration of cryogenics distribution, vacuum, RF and beam instrumentation systems. Following displacement of substantial loads in the linac hall, careful reconstruction of the LT alignment network had to be carried out, in addition to alignment of the newly installed or displaced elements and alignment correction of the old ones. The machine is now ready for both a quick recommissioning in view of a restart of users' operation (June 2019) and dedicated weeks for deep investigations of beam acceleration in the linac in view of its use as SPES re-accelerator.

A further upgrade of ALPI is foreseen for year 2021, when two additional QWR cryostats will be added at the end of the linac (in positions CR21 and CR22) so as to increase the final energy to ~ 10 MeV/A for ions of interest (in the $A=80 \div 160$ range).

The upgraded ALPI layout is shown in Fig.1, where the future three injection lines are highlighted, together with the displaced PIAVE cryostats and the high energy cryostats CR21 and CR22.

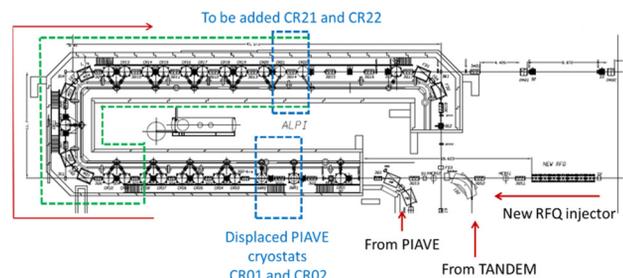


Figure 1: New ALPI layout with highlights on the position of the new cryostats (in blue) and higher gradient triplets (in green). Injection from stable beams (Tandem and PIAVE) and exotic ones (SPES new RFQ injector), and the direction of the beam are marked by red arrows.

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PIAVE QWR CRYOSTATS MOVED TO ALPI

Two cryostats, equipped with 4 QWRs each, were moved from PIAVE to ALPI in May-June 2018. Once disconnected from PIAVE cryogenic plant they were reconnected to the ALPI one, with the support of a specialized company. During this preparatory work, on two subsequent occasions, weld leaks were found on the new valve boxes during tightness tests and their precise location was spotted through radiographic analyses. These unforeseen events delayed by a couple of months this part of the work, which was then satisfactorily concluded in December, when both cryostats were eventually cooled down to 4K. Liquid nitrogen and gaseous helium piping were adapted to the new configuration.

In February 2019, following the usual bakeout, room temperature and 4K conditioning, the performance of the QWR's was measured again (Fig.2), showing no degradation with respect to the performance of such resonators in PIAVE before the displacement.

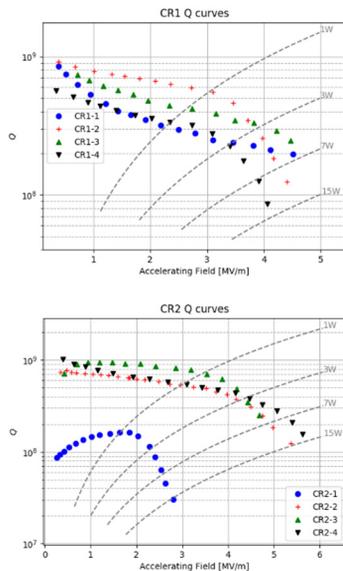


Figure 2: Resonator Q vs. E_a [MV/m] curves of cryostats CR01 and CR02 after their relocation in ALPI, showing no degradation with respect to their value in PIAVE before the displacement.

The cryogenic plant went through special maintenance, in the same time span: charcoal filter towers of two He compressors were replaced, as well as one compressor motor, and turbine cartridges together with broken T-sensors in the cold box. A vacuum leak on the cold box was fixed too. CR01 and CR02 were also equipped with liquid nitrogen lines for the refrigeration of the resonator couplers, a strong overcoupling of which is necessary for stable resonator operation beyond 3,5 MV/m.

UPGRADE OF ALPI FOCUSING

The ALPI linac had been designed in the early nineties for an average QWR accelerating field of around 3 MV/m, at a time when it was hard to conceive the extraordinary

boost in superconducting (sc) cavity performance of the next decade. An upgrade of ALPI resonators was indeed carried out between 1998 and 2004, ending in an average accelerating field exceeding 4,5 MV/m, with operational values larger than 6 MV/m for higher energy resonators in Nb/Cu. Larger accelerating fields induce coupling of the longitudinal and transverse phase spaces, leading to substantial beam losses along the linac [4]. These losses are concentrated in the two accelerating branches of the folded linear accelerator, which demand higher gradient focusing triplets than originally designed. For this reason, the replacement of 10 triplets with 50% higher gradient was planned in the SPES project, as a higher beam transmission is particularly relevant for the case of exotic beams which are characterized by a particularly low beam current (hundreds or even tens of fA). The 10 triplets involved in this upgrade, from 20 to 30 T/m, are highlighted in fig.1. Together with the triplets, new power supplies were purchased too. Fig. 3 shows pictures of an old and a new triplet, after installation. In addition to this upgrade, a new triplet (recovered from the old 20 T/m ones) had to be added in between cryostats CR01 and CR02, and a new BI box was added in this section too. A significant electric and hydraulic infrastructure work had to be carried out in parallel, then provisionally limited in scope due to a legal issue with the companies contracted for infrastructure work. Nevertheless, all new lenses and power supplies could be successfully tested individually at full field and prepared for beam commissioning.



Figure 3: Photo of the old type of triplets (20 T/m, left) and the new one (30 T/m, right).

ANCILLARY PREPARATORY WORK

Together with the upgrade of magnetic lenses and the displacement of cryostats, the relevant beam pipes, pumping system and vacuum control system were reconfigured to the new layout. Similarly, control systems for the new cryostats, cavities, magnets and BI stations were extended to the new elements.

At the conclusion of the assembly phase, before LT-aligning the new triplets and cryostats, a significant deterioration of the LASER tracking network was observed both in the PIAVE injector and in the lower energy part of ALPI,

on some instances by more than 2 mm, clearly induced by the heavy load displacement related to the relocation of the two cryostats and the removal of the related Pb shield from the PIAVE vault. Remake of LT alignment network in the vicinity of the interested area took 2 more weeks, added to the 4 planned for PIAVE and ALPI alignment. In the same time span, the correct alignment of cryostats was checked too, with the only CR14 having to be substantially corrected. At the end of the alignment campaign, an alignment precision close to $\pm 0,2$ mm was set for all beam line elements.

It should be noted that a thorough remake of the alignment network shall have to be performed, before SPES operation, in the appropriate conditions, i.e. at the end of the whole assembly in the hall and with all plants off. This was not possible this time, due to time conflict with the users' beam schedule.

ALPI RE-COMMISSIONING

In the framework of the upgrade of LNL superconducting linac ALPI for the SPES project, besides a quick beam commissioning to allow for prompt restart of users' operation (scheduled at the beginning of June 2019), ample time (a few weeks) will be dedicated to deep investigations of the machine setup in view of its future operation with exotic beams from the ADIGE injector.

Injection of the RIB line into ALPI will take place through the SPES normal conducting RFQ [5], currently under construction. We will provisionally use the PIAVE superconducting RFQ (SRFQ) injector PIAVE to simulate the behaviour of the new injection line. A new PIAVE layout was put in place following relocation of the two QWR cryostats [3], equipping the MEBT line (after the SRFQ) with three QWR's at 80 MHz, aimed at increasing, as shown in the simulations, the longitudinal acceptance of ALPI [6].

New techniques will be implemented and tested to handle radioactive ion beams (RIB) and maximize their acceleration and transmission. The main one will be the so called "blind-tuning" method. The RIB beam current is indeed expected to be lower than the sensitivity of standard BI tools; therefore, the machine will be first of all setup with a stable higher I beam, detectable with such instrumentation, with a small A/q difference with respect the RIB. After this machine setting, the ion source will switch to the A/q-close radioactive species and the accelerator is expected to deliver the beam up to experimental station with the previous machine settings. From the simulations, up to a 1/500 difference in A/q just a small increase of losses (a few percent) is expected. However, this needs to be tested experimentally. For such purpose, three ion species have been selected:

- $^{16}\text{O}^{3+}$, A/q = 5.33
- $^{136}\text{Xe}^{25+}$, A/q = 5.44, 1/50 difference in A/q, so large to require some scaling from the $^{16}\text{O}^{3+}$ case
- $^{109}\text{Ag}^{20+}$, A/q = 5.45, 1/545 difference with respect to $^{136}\text{Xe}^{25+}$

All three beams will be accelerated up to 8.6 MeV/A.

In the first part of these tests, the virtual accelerator software TracewinVA [7] will be implemented. The software is interesting from the beam optimization point of view, since it implements direct method algorithms. Moreover, it supplies an easy interface between the simulations and the real data of the accelerator. This last point is very important for benchmarking the actual machine. At present, substantial differences persist between simulated and actual transmission values (the simulated one is a factor 2 larger than the experimental one), which needs to be fully understood and fixed in ALPI prior to exotic beam acceleration.

Once these benchmarks will be satisfactory, it will be possible to proceed with the second part of the experimental campaign, when upgraded BI and of new digital RF controllers (much more precise in amplitude and phase) shall have been implemented: it will be possible to fully test the blind tuning routine and the scaling procedures. In this phase, measurement of the longitudinal acceptance of the ALPI complex, using the MEBT bunchers, is planned too. Digital RF controllers and upgraded BI will be operational in 2021.

CONCLUSION

Beam commissioning of ALPI from the PIAVE injector, following the herein reported upgrade, is planned for late May 2019. In Fall 2019, first scaling experiments will be performed (blind tuning), in view of becoming acquainted with techniques which will be mandatory for exotic beam operation. In 2021 a second ALPI upgrade phase is planned, with improved RF controllers, BI stations for fA beams and two additional cryostats at the end of ALPI to reach a final energy of ~ 10 MeV/A for A/q ~ 7 .

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