

# HARDWARE COMMISSIONING OF THE RENOVATED PIAVE INJECTOR AT INFN-LNL

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## Abstract

During 2018, the PIAVE superconducting linac injector at INFN-LNL, based on superconducting RFQs and two cryomodules with quarter wave resonators, underwent a renovation plan. This operation was strictly related to the one carried out on ALPI [1], which will become a post-accelerator for both stable and exotic beams in a near future. PIAVE Quarter Wave Resonator (QWR) cryomodules, in operation since 2006, were moved to ALPI to be used for the acceleration of both stable beams and future exotic beams delivered from the cyclotron target-ion-source station, after appropriate purification, charge breeding and pre-acceleration stages. In order to cope with the removal of the two QWR cryomodules in PIAVE, a newly designed 80 MHz room temperature buncher was designed, built and tested: the buncher is required so as to match the longitudinal phase space between PIAVE superconducting RFQs (SRFQ1 and SRFQ2) and ALPI. In the same period, substantial refurbishments on the ECR ion source platform were carried out, in particular on its infrastructure and safety equipment. A problem on an electronic component on SRFQ2, though quickly fixed, delayed beam commissioning of the PIAVE injector, which will start at the end of May 2019.

## INTRODUCTION

In April 2018, beam operation at the Tandem-ALPI-PIAVE accelerator complex in Legnaro was suspended, so as to concentrate manpower effort on the refurbishment of the ALPI linac in view of its exploitation within the SPES facility. Refurbishment of ALPI implied layout changes on the PIAVE injector as well, where two QWR cryostats have been removed and replaced with a third 80 MHz room temperature buncher, so as to keep the beam longitudinally focused after the SRFQs. The displacement of the QWR cryostats in ALPI was necessary so as to have them available from both the PIAVE and the new exotic beam injector.

Fig.1 shows a side view of PIAVE layout, before and after the herein described modifications.

SPES [2] is a second-generation ISOL-type facility for exotic beams, exploiting: a commercial proton cyclotron at 40 MeV with a 200  $\mu$ A intensity, as the driver accelerator; a UC<sub>x</sub> target with Surface Ionization, Plasma and LASER Ion Sources (SIS, PIS; LIS); a high-resolution mass separator ( $M/\Delta M \sim 20000$ ) preceded by an RFQ cooler; a charge

breeder and its associated Medium Resolution Mass Separator (MRMS); a room temperature 80 MHz RFQ, and an injection line, with two 80 MHz bunchers and quadrupole triplets, into the existing ALPI linac used as a RNB (radioactive nuclear beam) accelerator.

While building the rest of SPES, the layout of ALPI has been modified and refurbished, by displacing two QWR cryostats from PIAVE and increasing the gradient of 10 quadrupole triplets by 50%. In their new positions (CR01 and CR02) the displaced resonators will be available for acceleration from both the old stable beam injector PIAVE and the new ADIGE exotic beam injector.

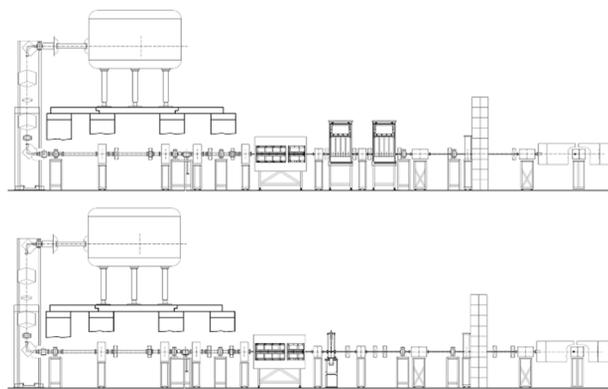


Figure 1: Modification of the PIAVE layout, where two cryostats (above), moved to ALPI, were replaced by a new room temperature 80 MHz QWR buncher (below).

The PIAVE injector, deprived of the relocated QWR cryostats, will continue to serve as ALPI stable beam injector.

Beam dynamics of the modified PIAVE layout will be shortly described. The removal of the cryostats required implementation of a third 80 MHz normal conducting buncher cavity, right after the recently upgraded SRFQs [3], so as to match the longitudinal phase space at the entrance in ALPI. The buncher has been fully characterized and conditioned, and prepared for beam operation.

During the 1-year long shutdown, substantial ameliorations on the ECR ion source and its platform were also carried out and are herein reported

Following displacement of heavy loads in the linac hall, related to the cryostat relocation from PIAVE to ALPI, careful reconstruction of the LASER tracking (LT) alignment network in PIAVE and ALPI had to be carried out, in addition to element alignment on the beam line.

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During the setup of the SRFQs, following their conditioning at 4K and prior to beam operation, the VCX (Voltage Controlled Reactance) fast tuner of SRFQ2 suddenly stopped operating. The issue was promptly solved but the whole restoration process required 1.5 months, thus delaying beam commissioning of both PIAVE and ALPI.

PIAVE is now ready for a quick recommissioning with ALPI in view of a restart of users' operation, scheduled for early June 2019.

## THE NEW PIAVE LAYOUT

Removal the 8 QWRs after the superconducting RFQs asked for the implementation of an additional 80 MHz buncher, to keep ions bunched in the longitudinal phase space, i.e. in a  $\pm 20^\circ$  phase range. This basilar function is done by the purposely developed 80 MHz QWR, with an accelerating field of 650 kV/m for  $A/q=6.95$  (e.g.  $^{132}\text{Sn}^{19+}$ ).

The three bunchers and transverse focusing elements prepare the beam longitudinal and transverse phase spaces to match the acceptance of the ALPI linac, avoiding beam losses in its initial low- $\beta$  part [4].

Fig.2 shows the transverse and longitudinal beam envelopes from the exit of the PIAVE SRFQs to the ALPI linac.

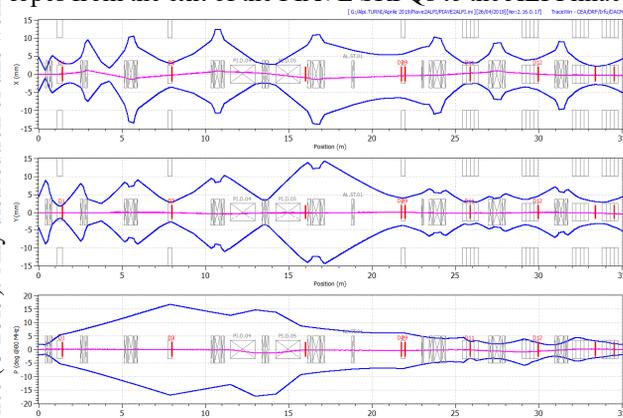


Figure 2: Beam envelopes in X, Y and phase are shown with the maximum amplitude (2,4 the RMS value), from the SRFQ exit to the end of CR03. Nominal losses for the accelerated particles from the SRFQ exit to the experimental halls are kept below 1% (ideal linac case).

## THE NEW 80 MHZ BUNCHER

The newly developed room temperature 80 MHz buncher (Fig.3) is also the prototype of the two additional bunchers, in construction at present, which will match the longitudinal phase space between RFQ and ALPI on the SPES beam line. It features an inner diameter of 295 mm and a height of 1135 mm, for 20 mm long accelerating gaps. The design maximum gap voltage is 70 kV, corresponding to a maximum surface field of 0.65 MV/m. With a calculated Q value of 10900, the total power loss of 1.72 kW is concentrated almost fully on the water cooled central conductor.

The buncher has been built, installed and fully tested and is now ready for beam operation. RF conditioning started with  $30\mu\text{s}/1\text{ Hz}$  pulses at the nominal 2kW power, the duty

cycle was progressively increased to CW in 4 hours keeping the residual pressure below  $1 \times 10^{-6}$  mbar. After another 2 hours of automatic RF treatment with 0-to-100% voltage ramps, all power levels were overcome except two low power ones (at 30 and 40 W) which do not hamper their regular operation. At 2.13 kW, a gap voltage in excess of 100 kV is achieved, which is larger than the specified value. The unloaded Q was measured to be  $Q_0=8910$ .

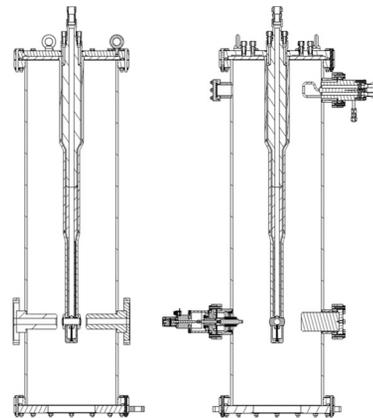


Figure 3: Cross sections of the new 80 MHz room temperature buncher; beam ports can be seen on the left hand image, while RF coupler (above) and fixed and movable tuners are visible on the right hand side.

## ON THE ECR ION SOURCE AND ITS PLATFORM

Taking advantage of the 1-year stop imposed by the ALPI upgrade plan, the PIAVE ECR ion source and its high voltage platform underwent an ample technical and infrastructural maintenance after about a decade of operation. The work regarded first of all the plants on the high voltage platform, with a rationalization of the electrical distribution, the replacement of all the cables, a modification of the extinguishing system of the insulation transformer, remaking the water cooling systems for source and extractor and upgrading the distribution of compressed air. An important part regarded the vacuum system, with the installation of a new common exhaust for the five turbo pumps mounted on the platform, as well as the realization and installation of a brand new control panel for vacuum management. Moreover, two new PLCs were installed and cabled to control devices at different voltage. Finally, as a temporary replacement of an existing emittance box, presently installed on the ADIGE injector beam line for its commissioning phase [5], a vacuum tube with horizontal slits was machined at the LNL mechanical workshop and mounted.

At the end of the maintenance period, the functionality tests of the ECR ion source and the platform were carried out: in particular, conditioning of all high voltages and oxygen beam production tests. The latter, normally used as an indicator if the performances of the ion source might have deteriorated for any possible reasons, gave a positive outcome. In view of the PIAVE commissioning phase, a test of xenon production was then carried out: a spectrum is

shown in Fig.4, zoomed on the xenon charge state distribution. Considering the limited time dedicated to the conditioning phase, the spectrum is very promising because it shows almost the best performances ever observed with this ion source, that now can be considered operational again and ready for the beam commissioning phase.

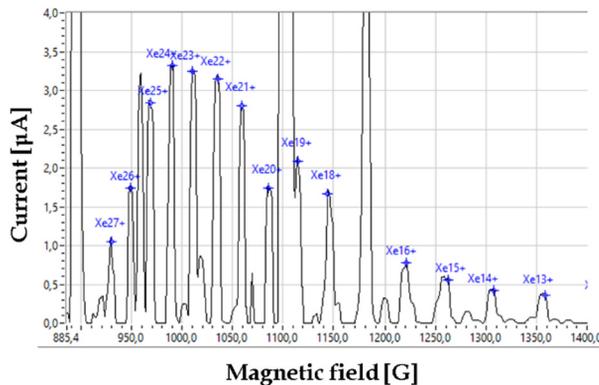


Figure 4: xenon charge state distribution obtained with the ECR ion source just after the conditioning phase.

## PREPARATION FOR PIAVE RE-COMMISSIONING

In preparation for linac re-commissioning after the upgrade operations, the following actions were also made: beam tubes and vacuum systems were adjusted; control systems of magnet power supplies and vacuum pumps were adapted to the new layout; alignment of the new buncher and alignment check of all elements of the beam lines were carried out. Eventually, SRFQs were refrigerated, RF conditioned and prepared for  $\phi$  and A locking.

### Alignment Issues

After relocation of the PIAVE QWR cryostats and removal of the local Pb radiation shielding, deterioration of the LASER tracking network was observed both in PIAVE and in the lower energy part of ALPI: walls moved, on some places, by more than 2 mm. The network was hence fixed and accelerating and focusing elements were then corrected to a precision of around  $\pm 0.2$  mm.

### Issues with the SRFQ2 Fast Tuner

During the very final phase of PIAVE and ALPI setup for beam commissioning, at the beginning of April 2019, after a few days RF processing at 4K and 24 hours of  $\phi$  & A locked operation at the field required by the tests ( $\sim 65\%$  of the specified maximum one) the VCX fast tuner (FT) [6] of the second superconducting RFQ ceased working.

VCX fast tuners are based on fast switching of two capacitances by means of 10 pin diode switches (PDS) to change the total impedance at the coupling loop, and switch a quite high reactive power (10-30 kVA) at 25 kHz with a duty cycle variable between 5 and 95%. By varying the duty cycle, the average effect of the resonator mechanical vibrations on the cavity resonant frequency  $f_0$  can be phase-controlled within a window  $\Delta f \sim \pm 100$  Hz. If a PDS

breaks in the closed position, a procedure has been envisaged to blow a fuse, connected in series to each diode, excluding it from the operation.

In this latter instance, unlike all other cases since inception of SRFQ operation in 2004, the fuse-blowing procedure did not solve the problem. The issue was diagnosed to be located at the location of the tuner itself and the feed-through itself was hence exonerated. VCX fast tuners, kept in a liquid He bath at 77K, are mounted on the body of the resonator itself through a thin stainless steel transition which keeps their thermal load towards the 4K environment to a reasonable minimum: its inner maintenance hence implies warming up and venting the cryostat, performing the intervention, and then repeating the whole cavity preparation cycle almost from scratch. The intervention was made in April 2019. As soon as the FT cover was removed, the cause of the problem was clearly detected in a short circuit between one of the wires connecting the common cathode rail, hosting command circuit and bypass capacitance, and the bottom of the FT cover (see Fig.5, left-hand side).



Figure 5: Broken FT on the left (1. damaged wire; 2. common cathode rail; 3. burnt inner side of the FT case); on the right-hand side, repaired VCX with new electric components and shorter wires (with fiberglass insulation).

After completion of the repair work, the VCX features were measured again, both at room T and at 77K: the measured operational frequency window of the fast tuner was  $\Delta f = 177 \text{ Hz} \pm 1\%$ , which is adequate for operation requirements and consistent with original specifications.

### Plan for Beam Tests

Quick recommissioning of the PIAVE injector will take place at the end of May. Having the SRFQ not moved since their latest operation shift, the phase between the two should not have changed. Therefore, both can be switched on at the field requested by the A/q value of the ion to be accelerated. The field of SRFQ2 was recalibrated electronically, after the intervention on the VCX and the related temporary removal of the RF coupler and pickup antennas: therefore small changes of the SRFQ2 field could be required in order to achieve maximum relative transmission at the end of ALPI. Switching on the 3-harmonic buncher upstream the SRFQs should then increase the final beam current by a factor 3, allowing the SRFQs to approach the design beam transmission of  $\sim 65\%$ .

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