BEAM COMMISSIONING OF THE SUPERCONDUCTING RFQS OF THE NEW LNL INJECTOR PIAVE

A. Pisent, G. Bisoffi, D. Carlucci, M. Cavenago, F. Chiurlotto, M. Comunian, E. Fagotti, A. Galatà, M. Poggi, A.M. Porcellato, M. Sattin, INFN - Laboratori Nazionali di Legnaro, Italy, T.V. Kulevoy, ITEP, Moscow, Russia

Abstract

PIAVE is the new injector of the LNL superconducting heavy ion linac ALPI; the injector is able to accelerate ions up to U (A/q=8.5) with a final energy of more than 1 MeV/u. During the last two months of 2004 the superconducting RFQ, composed by two Nb structures operating at 80 MHz, has been commissioned using the O^{3+} and Xe^{18+} beams produced by the 14.4 GHz ECRIS Alice. The beam has been accelerated up to 587 keV/u reaching the main design parameters (energy, transverse emittance, transmission) and demonstrating a stable and reproducible operation. This is the first operational beam accelerated by a superconducting RFQ.

INTRODUCTION

The injector PIAVE (see Fig. 1) is a linear accelerator able to deliver a wide range of positive charged ions, with energy of about 1.2 MeV/u, to the superconducting accelerator ALPI in operation at LNL. Respect to the present configuration, with the superconducting linac injected by the XTU Tandem (15 MV at the terminal) the performances will be improved in terms of beam current and ion mass available (up to uranium).

The main components of the injector are the ECR ion source (installed on a 350 kV platform) the LEBT (Low Energy Transport) beam line, the cryomodule housing two superconducting RFQs, the QWR linac section (two criomodules housing four cavities each) and the HEBT (High Energy Beam Transport) injecting into ALPI. The linac operates at 80 MHz, the bunching frequency is 40MHz.

The source platform and the LEBT have successfully been commissioned in 2000 [1] installing a temporary measurement (TM), able to measure the transverse emittance, beam current, pulse length and beam energy, at the RFQ entrance location (about 20 cm after the nominal electrode beginning).

In autumn last year the installation of the linac was completed and we commissioned the RFQ section alone by removing the first QWR cryomodule and installing the TM at its place. After two weeks of RFQ commissioning we reinstalled the QWR cryomodule and test the entire linac. In this paper we focus on the RFQ beam tests, since the test of the second part of the linac is still going on.

THE LEBT AND THE SOURCE

Beam tests at the end of the LEBT were again performed in September 2004, so as to check the transport features before RFQ installation.

Ion source beam extracted with a typical V_s=11 kV voltage (total current Is≅0.5mA) is mass separated (resolving power m/Δm≅100) and finally accelerated by an electrostatic column up to the nominal β=0.00892 for RFQ injection. For a typical $^{132}Xe^{18+}$ beam we have a platform voltage V_p=270 kV with a 17 Vpp ripple. Production of beams from metallic elements ($^{63}Cu^{11+}$, $^{107}Ag^{18+}$, $^{120}Sn^{19+}$, Pr^{18+}) was recently demonstrated. For the RFQ beam commissioning two beams have been used, O^{3+} and $^{132}Xe^{18+}$, requiring respectively 62% and 86% of the nominal platform and RFQ intervane voltage.

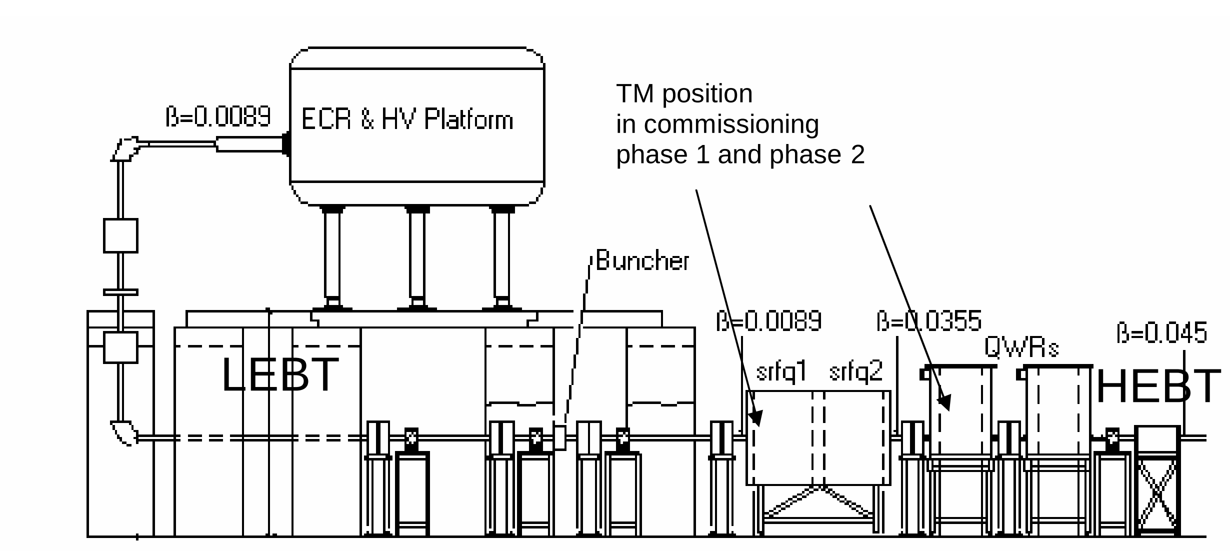

Figure 1: Layout of injector PIAVE.

The overall transmission of the LEBT was confirmed to be between 85 and 90%. The beam emittance is matched to the RFQ acceptance in both planes (Fig. 2); in vertical direction there is a residual vertical misalignment that has been lately corrected by looking at the RFQ transmission (see later).

Beam is pre-bunched before RFQ injection by a three harmonic buncher (40-80-120 MHz)[2]. The beam current bunch length at the RFQ input was measured by means of a micro channel plate, and was less than 500 ps.

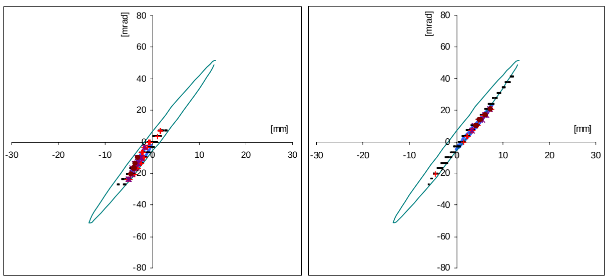

Figure 2: $^{129}Xe^{17+}$ at LEBT end. E=4766 KeV, ε_x=0.0445 mm-mrad, α=-3.6, β=0.87 mm/mrad (left), E=4766 KeV, ε_y=0.0456 mm-mrad, α=-10.37, β=2.88 mm/mrad (right).

THE SUPERCONDUCTIVE RFQS

As mentioned the RFQ part of PIAVE consists in two superconducting RFQ resonators. This original choice allows a very efficient acceleration (more than 2 MV/m for A/q=8.5) employing an innovative beam dynamics design[3]. The main specificity of a superconducting RFQ (SRFQ) is the possibility to employ an intense intervane voltage that allows achieving a large acceptance and acceleration. Moreover in this case the use of two separate structures, beside having clear construction advantages, allowed to further increase the voltage in the second SRFQ; the inter-vane voltage is 148 kV in SRFQ1 and 280 kV in SRFQ2 for A/q=8.5. The transition between the two RFQs (about 200 mm long) can be done without a reduction of the transverse acceptance thanks to the use of a suitable termination of the vanes at the end of SRFQ1 and at the beginning of SRFQ2. Moreover the transition is such that some additional acceleration is given to the beam in the fringe field region.

The first tuning of the two PIAVE SRFQs was done with O^{3+} beam and the external buncher off, recording beam transmission (on FC) and energy spectrum (on Si detector) for different phases of SRFQ2. The results are shown in Fig. 3. The nominal energies are 5.45 MeV for SRFQ1 and 9.4 MeV for SRFQ2. It should be noted that the quadrupole doublet 2PQ1, located after the RFQ and before the TM, determines a certain energy selection due to chromaticity. This effect is taken into account in the PAMTEQM-PARMILA[4,5] simulations superimposed to the measurements in Fig. 3. Simulations and measures match very well in the phase range in which the SRFQ1 beam falls within the separatrix SRFQ2, allowing a precise determination of the nominal SRFQ2 phase.

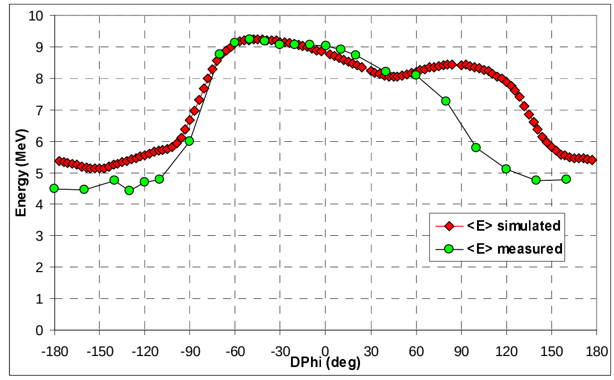

Figure 3: Average spectrum energy at RFQ exit as a function of phase difference between cavities.

After this, the buncher was switched on to the nominal voltages and adjusted in phase so to reach the maximum transmission. The values of transmission reached in December 2004 were in the 40-45% region.

This value of transmission was in disagreement with simulations that predicted a 20% more than that. It was then decided to realign the LEBT respect to the RFQ, checking both with optical devices and with best beam transmission. In Fig. 4 the results of this rather tedious operation are shown; for various positions of the last quadrupole doublet of the LEBT, each point corresponds to the best transmission optimised respect to the values of many parameters, like steerer fields and cavity phases. At the end of this process the beam transmission predicted by simulations was achieved.

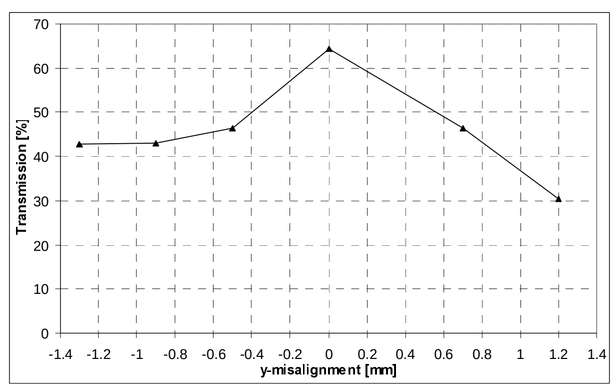

Figure 4: Beam transmission after vertical realignment of the LEBT.

In Fig. 5 is shown the energy spectrum out of the RFQ. The peak is broader than foreseen by simulations; a contribution to this value can be instrumental; indeed the preliminary experience the QWR acceleration show a very good transmission for the accelerated beam, only compatible with a good longitudinal emittance. An independent energy measurement with magnet spectrometer will be available soon.

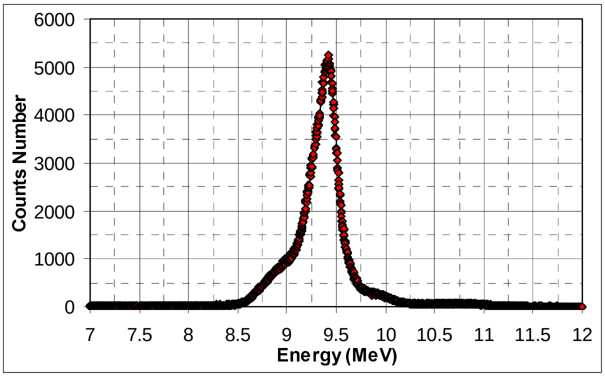

Figure 5: Energy spectrum out of the RFQ.

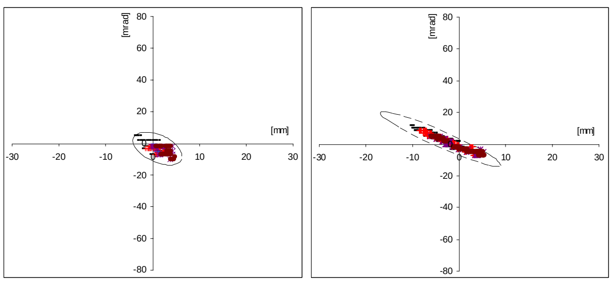

Figure 6: Horizontal and vertical emittance after the RFQ, $^{16}O^{3+}$ Energy = 9400 KeV, $\varepsilon_{rms,n.x}$= 0.1093 mm-mrad α=0.557 β = 0.58 mm/mrad and $\varepsilon_{rms,n.y}$ = 0.1205 mm-mrad α = 2.916 β = 2.309 mm/mrad.

Transverse emittances after the RFQ are shown in Fig. 6. These values, as for the LEBT, are measured using a slit and a grid at fixed distance, moved together by a stepping motor for each plane, either the horizontal or the vertical, at a time. The beam profile monitor "wires" are actually little bars of tungsten, 0.4 mm thick, we have 77 bars (spaced by 0.6 mm) for each plane. The distance between the slit and the beam profile monitor plane is 300 mm, so an angular accuracy of 3 mrad is reached. The whole angular divergence covered is 231 mrad. The slits are made by tungsten with a 100 μm wide aperture and they are sticked to a piece of copper to dissipate the generated beam heat. For the beam measurements after the RFQ the effective step size was reduced by mounting two grids shifted by half step-size (0.5 mm), as shown in Fig. 7.

Figure 7: Beam profile monitor with a double grid reducing the effective step size to 0.5 mm.

PERSPECTIVES

The main SRFQ characteristics have been demonstrated. Oxygen Beam currents up to 1μA have been transported through the RFQ showing a reliable and steady behaviour of the cavities. We believe that the demonstration of SRFQ beam operation opens rather wide perspectives for a new generation of CW RFQs with larger accelerating field and transverse acceptance.

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