THE NEW RFQ AS RIB INJECTOR OF THE ALPI LINAC

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Abstract

At the Legnaro National Laboratories it is operating a Super Conducting linac for nuclear studies named ALPI. A new project SPES is under study to provide neutron-rich rare nuclear beams (RIB) of final energies in the order of 10 MeV/A for nuclei in the A= 9-160 mass region. The radioactive ions will be produced with the ISOL technique using the proton induced fission on a Direct Target of UCx and subsequently reaccelerated using a new injector for the ALPI accelerator complex. In this paper the new RFQ injector and the transport line to ALPI will be describe.

BEAM DYNAMICS

Within the project SPES laboratory a new injection line will be built at INFN LNL to transport and match the RIB to the existing ALPI superconducting linac [1][2].

This line includes a new RFQ (see Table. 1) that will operate in a CW mode (100% duty factor) at a resonant frequency of 80MHz. This frequency is the same of the lowest energy ALPI superconducting structures. The injection energy of ions was set to 5.7 keV/u. This choice is a compromise between the desire to reduce the ion energy to simplify the LEBT and the RFQ bunching section design and the need to increase the injection energy to increase the beam rigidity in the spectrometer and to reduce space charge effects. The extraction energy was set to 727 keV/u (respect to the 588 keV/u of the present super-conducting RFQ, named "PIAVE"), to optimize the beam dynamics of the SRF ALPI linac.

Table 1: Principal RFQ Parameters

Parameter (units)	**Value**
Operational mode	CW
Frequency (MHz)	80.
Injection Energy (keV/u)	5.7 (β=0.0035)
Output Energy (keV/u)	727 (β=0.0395)
Accelerated beam current (μA)	100
Charge states of accelerated ions (Q/A)	7 – 3
Internal bunching section	Yes

The design goals were to minimize the longitudinal and transverse emittances growth and to optimize the RF losses and transmission of the RFQ structure. The RFQ cells were created using a home-made program, based on the program used for the design of CERN linac3 RFQ, the multiparticles transport has been done by PARMTEQM code package and TraceWin/Toutatis. With this design the RF power consumption is minimized, while a linear voltage profile, allows accelerating the beam more effectively at higher velocities and achieving a shorter RFQ. A transition cell was used at both the entrance and exit of the RFQ. Table 2, Figure 1 and Figure 2 show the main parameters of the RFQ. The RFQ transmission is more than 95% of accelerated particles, the final longitudinal RMS emittance is 0.15 nskeV/u. The 99% longitudinal emittance is 1.2 nskeV/u.

The transverse phase advance (σt0) is kept constant in the RFQ shaper, while in the Gentle buncher is decreasing, due to the rapid increase in the longitudinal phase advance σl0, the limit on σl0 is to limit the effects of the fast resonance when σt0= σl0, in Figure 2 the effects of the resonance is enhanced by using a 6σ gaussian distribution. In the accelerator part of the RFQ the increase of R0 and the increase of acceleration produce the effects of decreasing the σt0 and σl0.

Table 2: RFQ Design Parameters

Parameter (units)	Design
Inter-vane voltage V (kV, A/q=7)	63.8 – 85.84
Vane length L (m)	6.95
Average radius R_0 (mm)	5.33 – 6.788
Vane radius ρ to average radius ratio	0.76
Modulation factor m	1.0 – 3.18
Min small aperture a (mm)	2.45
Total number of cells	321
Synchronous phase (deg.)	-90 – -20
Focusing strength B	4.7 – 4
Peak field (Kilpatrick units)	1.74
Transmission (%)	95
Input Tr. RMS emittance (mmmrad)	0.1
Output Long. RMS emittance (mmmrad) / (keVns/u)/(keVdeg/u)	0.055 / 0.15 / 4.35

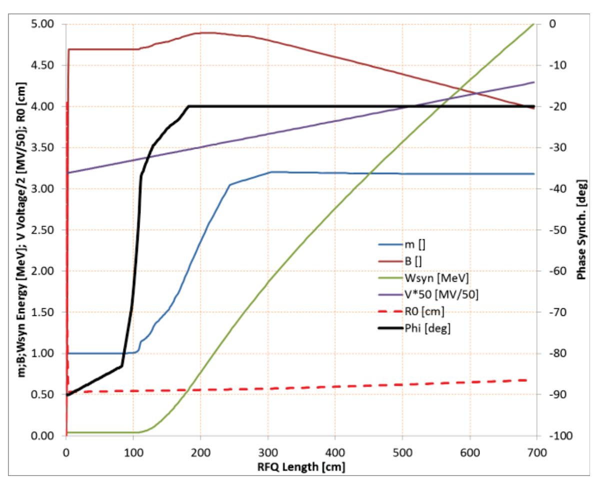

Figure 1: The main RFQ parameters vs. length.

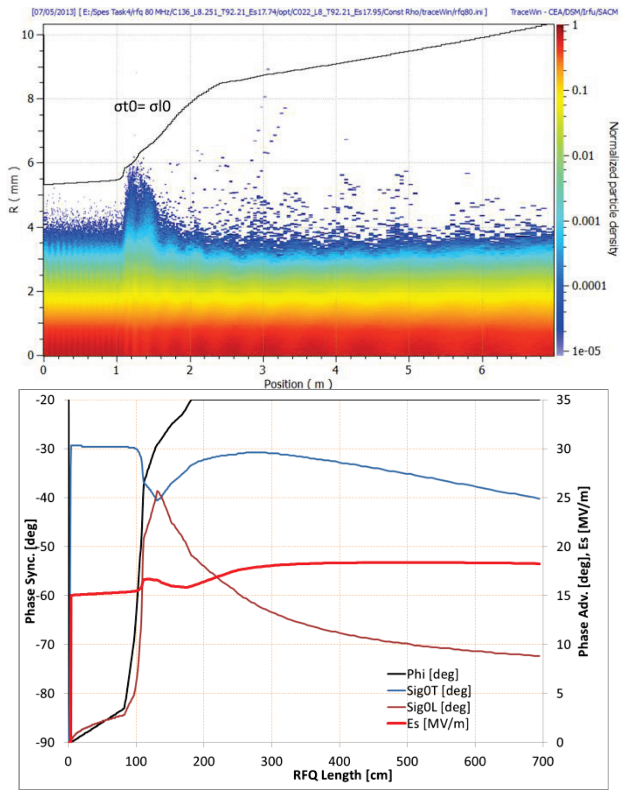

Figure 2: In the upper part the Radial density along the RFQ, in the lower part the phase advance, synchronous phase and Surface Field along the RFQ.

SENSITIVITY STUDY

The RFQ will be used for injection in the ALPI linac with RIB beams at very low intensity and with stable beam with quite large intensity of tens of uA.

The RFQ design is able to transport an RMS emittance of about 0.15 mmmrad norm. with a 90% transmission, calculated on a 6σ Gaussian distribution, see figure 3.

The RFQ voltage must be stabilized in a range of +/-2% to avoid an increase of losses, see Figure 4.

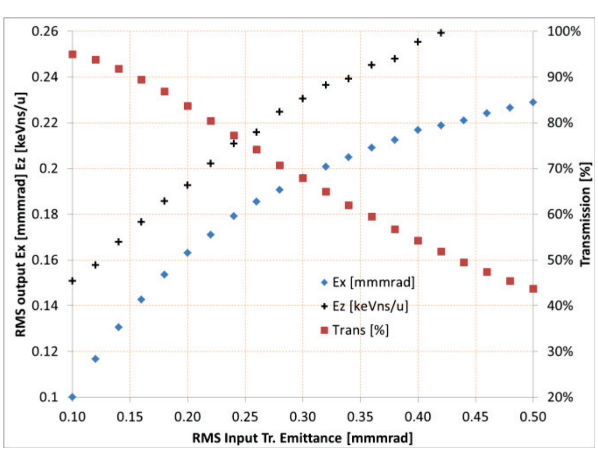

Figure 3: Output emittances as function of input emittance.

The RFQ has a low mass filter property all masses with a difference in mass below 60 will be accelerated with a transmission of more than 75%.

The RFQ limit on current is about 400 uA, to avoid more than 10% losses.

A full mechanical errors study will be performed with the method defined for the IFMIF RFQ [3] in connection with the mechanical module length.

CONSTRUCTION CONCEPT

The construction considered for SPES RFQ is a four vane structure, divided in 7 modules of approximately equal length. The cylindrical tank (800 mm diameter) is in copper plated stainless steel 308L properly annealed. The electrodes are built out of OFE copper and stainless steel 308L; brazing under vacuum is used to build the cooling channels and the interface reference surfaces between electrode and tank.

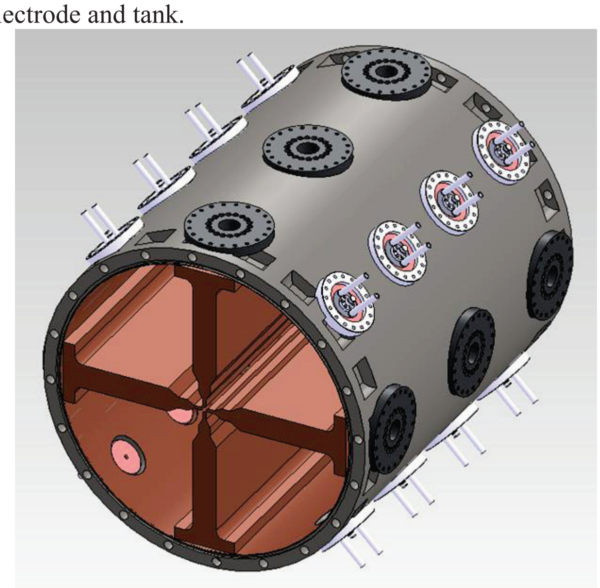

Figure 4: Mechanical layout of the RFQ tank module of about 1 meter.

The electrode modulation is milled to final value after brazing, and as the last operation the electrodes are positioned, aligned and bolted to their final position in the tank. Vacuum tightness is guaranteed at electrode bases by circular gaskets, that can be inspected and substituted without removing the electrode. The RF joint is at the electrode bases, with a current limited to less than 20 A/cm even in the undercut region.

RF STUDY

In order to obtain a linear voltage profile along the RFQ it is required that the cavity terminations need to be properly detuned of an equal amount in order to get the correct value of dV/dZ @z=0 and z=L. Therefore, as for the shape of each RFQ section is concerned, it is sufficient to obtain the same cut-off frequency for all of them. For such a purpose, and with the aim of easing the machining of the electrode, it was decided to vary the

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dimension Y4 of Figure 5 [4], in such a way that the TE21 frequency variation due to R0 variation can be compensated. Such quantity varies from 27 mm in the Low Energy part of the RFQ to 19.5 mm in the High energy part. The electrode width is kept constant and equal to 24 mm in order to accommodate the cooling channel.

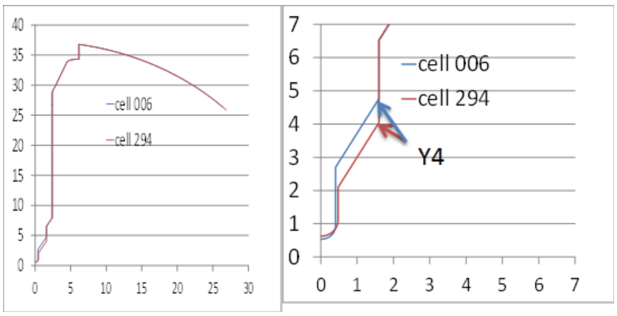

Figure 5: 1/8 of RFQ (right) and the frequency adaptation zone (left). The maximum value of the H field is 1630 A/m.

As for power consumption calculations is concerned, it has to be pointed out that the total power P_{RF} is related to the 2D power calculated by SUPERFISH, PSF, by means of the relationship

$$P_{RF} = P_{SF}\alpha_{3D}\alpha_{RF}$$

Where α_{3D}=1.3 is a factor that takes into account the 3D losses, α_{RF} = 1.2 takes into account the margins for RF System (losses in the lines and in the circulator, finite bandwidth of the amplifier etc). In the following table the main RF parameters are shown.

In the following Table 3, the main RF parameters of the RFQ are summarized

Table 3: Main RF Parameters

Shunt Impedance (SF)	538-552	kΩ·m
Q0 (SF)	20000	
Copper power (SF)	73	kW
Stored Energy	3.0	J
Max H field (2D)	1633	A/m
Max Power Density (2D)	0.31	W/cm^2
Total Power	113	kW

The RF power will be fed by a single amplifier unit based on a TH535 tube (180 kW max power in CW).

The vane terminations and undercuts correspond to the maximum power density, and have to be properly cooled. Moreover with bolted electrodes one has to be careful about the maximum current across the RF joint at the bases of the electrode. The design proposed is such to keep the current density always below the value of 2d cross section.

HFSS simulations showed that, actually, on the electrode base, where the RF joint is foreseen to be inserted, the maximum current does not exceed the 16 A/cm 2D values.

INJECTION INTO ALPI

The PIAVE-ALPI complex is able to accelerate beams up to A/q = 7 [5]. Higher A/q ions suffer from too low injection energy to the medium-β cryostats, where the RF defocusing is too strong and the beam gets easily lost onto the cavity beam ports for this purpose a new RFQ injector will be used. In the last years the average cavity accelerating field has been enhanced by more than a factor of two with respect to the original design value but the strength of the focusing lenses on the other hand, has remained the same (20 T/m). Therefore, even for 6 < A/q < 7 it is hard to design a proper longitudinal beam dynamics such that it will not cause problems on the transverse plane.

For SPES, the Radioactive Ion Beam at 727 keV/A will be injected into ALPI by means of the QWRs actual present into PIAVE, see Figure 6 and the envelopes in Figure 7, by using this layout and with the help of the new RFQ the losses in the ALPI linac are reduced at about 6%: 3% in the first branch of the linac and the other 3% in the high energy branch of the ALPI linac.

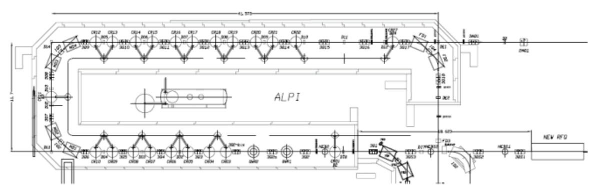

Figure 6: Layout of ALPI with the SPES RFQ as Injector.

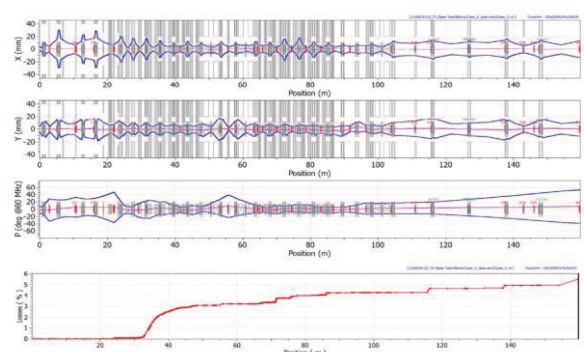

Figure 7: Multiparticles envelopes of the ALPI and losses, with the beam coming out from the SPES RFQ, from left to right.

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