STATUS OF THE SUPERCONDUCTING RFQ PROJECT FOR THE LEGNARO NEW POSITIVE ION INJECTOR

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Abstract

The new positive ion injector for the ALPI Complex upgrading has been founded and is in its design phase. The aim of the injector is to accelerate ions with masses of the order of 200 and high charge states from the ECR source to ALPI covering the β range 0.009 to 0.055. The chosen structures are two superconducting RFQ's operating at 80 MHz, followed by QWR's at the same frequency. The paper describes the state of the project starting from the beam dynamics and the cavities design and covering all the technological aspects.

1 INTRODUCTION

At the Laboratori Nazionali di Legnaro (LNL) the superconducting post- accelerator ALPI is currently fed by beams coming from the 15 MV XTU tandem. In order to increase the capability of the complex towards the very heavy ion mass range a new low energy superconducting accelerator called PIAVE (Positive Ion Accelerator for Very-low Energy) has been designed. This upgrading of the Legnaro complex , together with the construction of a third experimental hall served by two novel beam transport lines from the tandem and from ALPI to the new hall [1], will allow the possibility of operating the two machines in parallel and therefore to run two different experiments at the same time. It will also cope with the increased user request for beam time due to the presence of the EUROBALL apparatus which will be host in Legnaro.

The new injector for ALPI uses the positive ion source (ECR) [2] already constructed at LNL.

Due to the higher charge states delivered by the ECR source an RF injector with an equivalent voltage of about 8 MV can substitute the 15 MV tandem as injector for ALPI with higher beam intensities and heavier masses.

The machine consists of two accelerating sections which are a Radio Frequency Quadrupole (RFQ) structure chain up to about 580 keV/u followed by independently phased Quarter Wave Resonators (QWR) [3]. This subdivision gives a good acceleration efficiency, allows the use of already developed QWR's and the possibility of a staging in the construction.

Last we mention that this one would be the first superconducting RFQ in operation. The choice is motivated by the need of a CW machine that uses the potentiality of ALPI; most of the experiments done at LNL use high efficiency detectors well matched with beam intensities of some particle nA and 100% duty cycle. On the other hand in our laboratory there is the expertise in superconducting resonators construction and operation, so that this is a natural choice.

2 BEAM DYNAMICS

Due to the high cost of a superconducting structure and associated cryostat, big emphasis has been given to the optimization of the average acceleration that is much higher then in other RFQs with similar surface field[4,5]. To achieve this an external bunching has been preferred to an adiabatic bunching within the RFQ. Moreover, as observed in ref [6], a high acceleration efficiency is possible with relatively large aperture and voltage. Having more then one RFQ the voltage can be increased (from one RFQ to the next one) so to compensate the inefficiency due to cell lengthening. The draw back of the voltage increase is that to control the resonators operating in a self excited loop the required rf power is proportional to the stored energy.

For these two competing requirements an RFQ with input energy above 600 keV/u, would either be very short or very inefficient. Moreover increasing R_0 the electrodes become very massive and the transverse focusing poor. For these reasons we use the QWRs (developed for the low β section of ALPI [7]) as soon as their transit time factor is high enough.

The details of the beam dynamics in the RFQ are mainly determined by the minimization of the longitudinal emittance increase. In particular the choice of a small $|\phi s|$ directly at the beginning of SRFQ1 would spoil the emittance due to the RF field non linearity. For this reason in the first cells of SRFQ1 we ramp the synchronous phase from -40 to -18 deg, and we increase slowly the modulation factor so to keep the specified transverse acceptance. In SRFQ2 the bunch is so short that we can keep ϕ_s=-8^0.

The transition between the two RFQs, with a drift length of 200 mm, causes a beam mismatching that has been minimized. Finally the two transport lines between the source and SRFQ1 and between the new injector and ALPI have been designed, with the proper transverse and longitudinal matching. In table I the main parameters of the new injector are listed.

Table I Injector parameters

Source and LEBT			
Ion source	ECR	14 GHz	
Mass to charge ratio	8.5-1		
Platform voltage*	350	kV	
Energy	41.2	keV/u	(β=.0094)
Beam emittance	0.5	mmmrad	(norm.)
Bunching system	DDDF	40-80	MHz
$\Delta\phi$	±6	deg	(80MHz)
ΔW	±0.55	keV/u	
RFQ Accelerator			
Radio Frequency	80	MHz	
Input Energy	41.2	keV/u	(β=.0094)
Output Energy	578	keV/u	(β=.0352)
Average acceleration*	2.16	MV/m	
Max. Surface E field*	25	MV/m	
Max. surface B field*	295	G	
Max. stored energy/RFQ*	≤4	J	
Acceptance	≥0.9	mmmrad	(norm.)
Output emittance	0.5	mmmrad	(norm.)
	≤0.7	nskeV/u	
	SRFQ1	SRFQ2	
Vanes length	134.7	76.3	cm
Output energy	341.7	578.3	keV/u
Voltage *	150	280	kV
Number of cells	41	13	
Average aperture R_0	0.8	1.53	cm
Modulation factor m	1.2-3	3	
Synchronous Phase ϕ_s	-40÷-18	-8	deg
Tank diameter	46	62	cm
Max. surface B field*	280	295	G
Shunt impedance Rsh/Q	22.7	23.7	Ωm
Quality factor Q	7e8	9e8	
Power dissipation (4K)*	≤7	≤7	W
QWR Section			
Number of resonators	8		
Output energy*	948	keV/u	(β=.045)
Radio Frequency	80	MHz	
Optimum β	0.05		
Accelerating Field	3	MV/m	
Shunt impedance Rsh/Q	3.2	kΩ/m	
Quality factor Q	1e9		
Power per cavity (4K)	≤7	W	
Synchronous Phase $\lvert\phi_s\rvert$	20	deg	
Matching Line to ALPI			
Number of bunchers	2	(room temperature)	
Effective Voltage VT	100	kV	

* The values are referred to a mass to charge of ratio 8.5, $^{+28}U^{238}$.

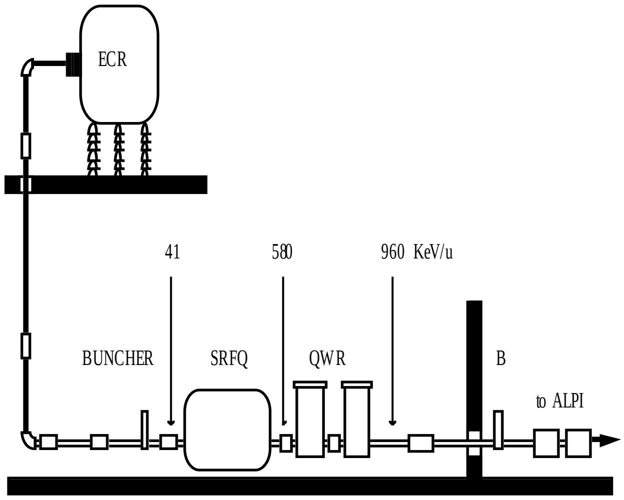

Fig. 1 Layout of PIAVE, not in scale.

3 THE SRFQ RESONATORS

The two SRFQ's resonators operates at 80 MHz and consequently the structure chosen is a four-rod realized with four modulated vanes supported by symmetric inductive posts [3]. The second resonator, now in its prototyping stage, is shown in figure 2. The two resonators are housed in the same cryostat in order to reduce to the minimum the drift between them for beam dynamics requirements.

The maximum surface electric field of 25. MV/m drove the selection of the niobium as superconducting material and the geometry of the internal structure suggested to use a niobium sheets e-b welded structure.

The rf parameters of the two resonators computed by M.A.F.I.A. codes [8] are summarized in table I.

The most demanding parameter, concerning the operation as superconducting cavities in self excited loops, is the rf energy stored. The upper limit of 4 J/cavity is dictated by the rf power needed for the phase locking. Actually the required active power to have a Δf feedback control bandwidth is given by: $P_a=2\pi U^*\Delta f$, where U is the rf stored energy. To have a routinely bandwidth of 20 Hz an active power of about 500W is required. It follows that the total power from the rf amplifier is of 1 kW [9].

The resonator geometry is the result of a detailed study of the mechanical behaviors of the resonator investigated by means of the 3D FEM code I-Deas [10], with a special concern to the mechanical resonating frequencies. The mechanical vibrations of the structure would change the natural rf frequency and it will be difficult to have an operating bandwidth of ±10 Hz with a reasonable rf power. Therefore the rigidity of the whole resonator is achieved using stiffening rings and bars on the outside of the resonator as well as optimizing the shape of the inductive supports. The mechanical resonant frequencies has been pushed higher than 150 Hz in a region where the first preliminary measurements did not show appreciable mechanical disturbances in the ALPI environments.

The tuning of the resonators is performed via a elastic deformation of the two end plates. The system gives a tuning range of ±100 kHz with a movement of ±2.5 mm of both the end plates.

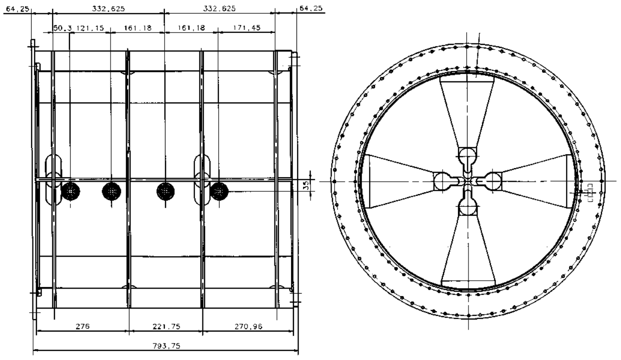

Fig. 2 SRFQ2 technical drawing

4 STATUS OF THE PROJECT

PIAVE is a three years project and it is now in its design and prototyping stage.

The ancillary systems for the new machine are an extension of the well proved ALPI equipment, such as the vacuum, the control systems and the diagnostics.

The rf system that operates the RFQ resonators is based on the ALPI rf systems developed for the 80 MHz QWR's but it requires 1 kW power amplifier for the phase locking as described above.

The liquid Helium needed for the cooling of the superconducting structure will be delivered by the ALPI cryogenic complex. The cooling power requirements for the whole machine, including the distribution lines, is of 130 W at 4.5K and 600 W at 80K. In order to avoid the overloading of the ALPI system it is foreseen to get the refrigerating power at 80K by a liquid Nitrogen cooling system. An important requirement of the system is the quietness concerning the mechanical vibrations.

The prototyping stage of the RFQ cavities started with the construction of a e-b welded stainless steel full scale model of the SRFQ2. The first electrodes has been welded to its supports, the other pieces of the resonator are under construction and an identical niobium resonator will follow immediately.

In order to be able to test the RFQ resonators a test cryostat is under construction. The liquid helium reservoir is such that the resonator is fully immersed in a Helium bath. The reservoir has been made out of Titanium to minimize the stresses due to the differential thermal contraction, the difference between the integrated thermal coefficient of the titanium is only 5% higher than the Niobium one.

As a side project a development of the magnetron sputtering of Niobium on Copper substrate for the RFQ structures is under investigation with the construction of a scaled 160 MHz resonator.

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