The New Superconducting Positive Ion Injector for the Legnaro ALPI Booster.

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Abstract

Following the demand of very heavy ion beams at the Laboratori Nazionali di Legnaro a new injector for ALPI is foreseen. At present ALPI is fed by a 16 MV XTU Tandem providing, routinely, beams up to masses of the order of 90 amu. In order to upgrade the possibilities of the complex and accelerate masses up to 200 amu the novel injector has been designed. The new machine consists of an ECR source on a high voltage platform, capable of 350 kV, followed by two superconducting RFQ resonators operating at 80 MHz and boosting the beam energy up to about 570 keV/amu. Downstream the SRFQ's eight Quarter Wave Resonators similar to the ALPI bulk niobium cavities are foreseen, to reach a proper ALPI injection energy of about 950 keV/amu. This paper describes the project.

Introduction

The new positive ion injector for the Legnaro heavy ion facility PIAVE (Positive Ion Accelerator for Very-low Energy) will increase the capability of the complex in delivering very heavy ion beams to the experiments. The user request, after more than a decade of operation of the XTU tandem, is to have very heavy ion beams with intensities of few particle-nA onto the target. The new machine will allow the simultaneous operation of the two main accelerators operating at Legnaro, the XTU tandem and the post accelerator ALPI, that are forced to work in alternative, at present, being the tandem the only injector for ALPI [1,2,3]. Figure 1 shows the PIAVE technical layout from the ion source to the injection in ALPI.

The beam is formed in the ECR source Alice [4] which is located on a high voltage platform and accelerated by the 350 kV applied voltage. As shown in figure 1 the HV platform is placed 4 m higher than the ALPI vault floor on a concrete support. This solution, dictated by the dimension of the platform and the required distances from the wall, calls for a transport line which displaces the beam by about 5 m in the vertical direction and about 2 m in the horizontal one [5].

The transport line contains the double-drift double-frequency bunching system operating at 40÷80 MHz for the proper injection into the SRFQ.

The first accelerating section of PIAVE which consists of two superconducting RFQ cavities housed in the same cryostat (see fig. 1.). The output energy of the RFQ section has been optimized with respect of the acceleration efficiency of the structure. Following the SRFQ's there are eight accelerating Quarter Wave cavities of the same type of the bulk niobium low-β section of ALPI[6], with some minor modifications in order to decrease the β_{opt} value from 0.055 to 0.05. The QWR's are housed in two cryostats and in between there is a quadrupole doublet for transverse focusing.

Downstream the accelerating sections of PIAVE there is the transport and matching line to ALPI which includes two room temperature bunchers (in fig. 1. only one of them is shown being the second one hidden in the chosen view).

The choice of using superconducting structure has been driven by the fact that ALPI is capable of running in CW mode, being itself a superconducting machine. This follows the traditional use of electrostatic machines in nuclear physics and fulfill the request of the high efficiency multi-array γ-spectroscopy detectors which need a beam intensity of some pnA with 100% duty cycle.

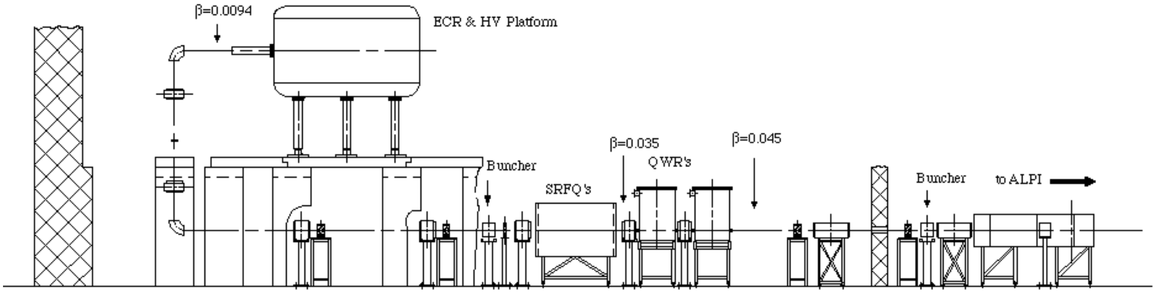

Fig. 1. The PIAVE layout

Table 1
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	mm mrad	(norm.)
Bunching system	DDDF	40÷80	MHz
Δφ	±6	deg	(80 MHz)
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. stored energy/RFQ*	^{2}4	J	
Acceptance	^{3}0.9	mm mrad	(norm.)
Output emittance	0.5	mm mrad	(norm.)
	^{2}0.7	ns keV/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)*	^{2}7	^{2}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	10^9		
Power per cavity (4K)	^{2}7	W	
Synchronous Phase $\lvert\varphi_s\rvert$	20	deg	
Matching Line to ALPI			
Number of bunchers	2	(room temperature)	
Buncher Eff. Voltage VT	^{2}100	kV	

Beam Dynamics

The new injector has to provide the very heavy ion beam for ALPI replacing the tandem, which means that the beam quality of the machine has to compete with the very good transverse emittance of an electrostatic machine. Moreover the longitudinal structure of the beam has to be acceptable for the injection into ALPI. These requests have to be combined with the optimization of the acceleration efficiency due to the very high costs of the superconducting structure and ancillary.

The main features of this design are the bunching of the beam outside the RFQ, the optimization of the acceleration efficiency with proper choice of voltages and apertures and the minimization of the output longitudinal emittance, that determines the modulation law[3,5,7].

The ion velocity for the transition between the RFQ structure and the QWR has been chosen balancing the acceleration efficiency of the two structures. Indeed at higher beam energy the rf stored energy in the RFQ becomes prohibitive, at lower beam energy the transit time factor in the two gaps QWR's is too low.

The result of the design study is summarized in table 1.

The Superconducting Structures

The project foresees two different resonators for the RFQ section for a total structure length of ~ 2.5 m, housed in a single cryostat mainly to reduce the unavoidable drift space between the cavities. We are forced to split the RFQ into two resonators otherwise the rf energy stored in the cavities would make the phase lock with a reasonable rf power amplifier impossible [3].

The first of the two cavities to be built is the second RFQ, named SRFQ2, because it is the most critical one concerning the rf electronics demands. The drawing of the cavity is shown in figure 2.

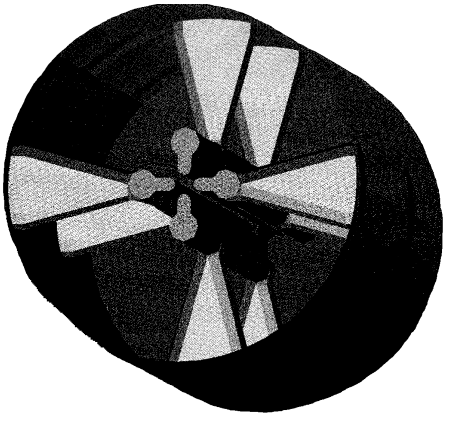

Fig. 2. The SRFQ2 resonator

The SRFQ's are made of e-b welded niobium sheets. The choice of this construction technology is advised by the tightness of the time schedule of the project, but a parallel

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

research experiment on the feasibility of this kind of structure in OFHC copper with a sputtered niobium film is in progress.

From the mechanical point of view, effort has been put in the calculation and modification of the eigenfrequencies of the mechanical vibrations of the cavities to minimize the effect on the rf operation[3,8]. The stiffening ribs and the bars push the mechanical resonant frequency to ~150 Hz, whereas the frequency without any stiffening but with the already optimized shape of the supports is ~50 Hz; this is more convenient considering the environment mechanical noise.

The SRFQ resonators will work in a self-excited loop mode and one needs a rf amplifier power of at least 500 W [3,9] in order to have a dynamic range of ±10 Hz, considering the quite high stored energy. This high rf power needed for the feed back control loop puts both rf and thermal constraints on the rf feed lines and on the cryostat.

The slow tuner range is of ±100 kHz, through elastic deformation of the two end plates by ±2.5 mm. A tuning system to compensate the ±50 mbar pressure variation of the liquid helium bath is under investigation.

As mentioned above, the second part of the accelerator is made of eight superconducting QW resonators operating at 80 MHz similar to the low energy section cavities of ALPI [6]. The only modification we foresee is the variation of the β_{opt} through modification of the beam port geometry. This minor change will not require a new study of the structure, that has been constructed and successfully tested.

Infrastructures

The most demanding ancillary system of the whole project is the liquid helium production and distribution system. PIAVE requires a cooling power of 130 W at 4.5 K and 600 W at 80 K and it is connected with the ALPI cryogenic complex. To avoid the overloading of the 80 K circuit the use of a separated liquid nitrogen refrigeration system is foreseen.

Another important constraint on the cryogenic system is the quietness concerning the mechanical noise because of the sensitivity of the SRFQ cavities to the vibrations. Different solutions are now under investigation ranging from an inexpensive system made of a dewar for the phase separation of the liquid helium to the use of superfluid helium.

All the other accelerator systems are an upgraded replica of the well proven ALPI systems [2].

The main novelty, concerning the beam diagnostics, is the design and construction of a beam emittance measuring box essential for the tuning of the transfer lines.

Status of the Project

PIAVE has been approved as a "Special Project" by the executive committee of INFN in its meeting of July 1996. It is a three years project with a cost of ~7.7 Billion Lit.

The feasibility studies of the project are going on since the middle of 1995 and in March 1996, before presenting officially the project to the INFN, an international committee reviewed the design in all aspects, giving scientific approval.

The SRFQ cavities are in a prototyping stage and the internal parts of the stainless steel full scale model of SRFQ have been e-b welded. The model is meant to check all the construction details of the cavities and to construct the proper mechanical jigs because the construction of the niobium cavity will immediately follow.

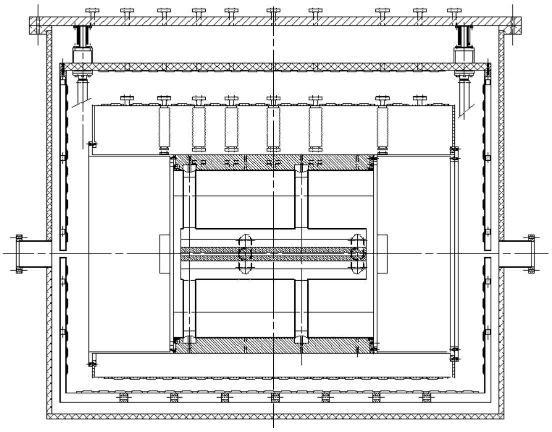

Fig. 3. The test cryostat and the SRFQ2 cavity

A test cryostat, able to house both the different SRFQ cavities, is under construction. The main feature of the design is the use of titanium for the liquid helium reservoir to avoid the stresses due to the different thermal contraction between the cavity, made of niobium, and the reservoir which contains it in a helium bath (see fig. 3.).

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