THE SUPERCONDUCTING SOLUTION FOR THE EURISOL DS POSTACCELERATOR INJECTOR*

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Abstract

In the framework of EURISOL design study, the superconducting solution for the Post-Accelerator injector foresees the use of two RFQs, one super-conducting and one normal-conducting, both operating CW at 88 MHz. After the multiple ionization in the ECR breeder on low voltage platform, the rare ions beam ($3 \leq A/q \leq 7$) is bunched at the main frequency by the NC RFQ without both losses and transverse emittance increase and accelerated afterwards through the SC RFQ up to 560 keV/u. A 8.8 MHz pulsed beam can be delivered to experiments placing a 3 harmonic buncher before the NC RFQ with overall beam losses lower than 25%. The beam dynamics results of the study of this solution as well as the main RF design and construction analysis of the main components are presented.

INTRODUCTION

The study on superconducting solution for the Eurisol post-accelerator injector has been completed, according to the official project schedule. In this solution, the injector foresees the use of two RFQs, one normal-conducting (NC-RFQ) and one superconducting (SC-RFQ), both operating CW at 88 MHz.

After the multiple ionization in the ECR breeder on a low voltage platform, the rare ion beam ($3 \leq A/q \leq 7$) is bunched at the main frequency (88 MHz) by the NC-RFQ, without any beam losses nor transverse emittance increase. It is then accelerated through the SC-RFQ up to 560 keV/u. The main parameters are listed in Table 1.

Table 1: RFQs main parameters.

	NC-RFQ	SC-RFQ
Frequency	88 MHz	
Ion m/q	3÷7	
Input energy	5 keV/u	88 keV/u
Output energy	88 keV/u	560 keV/u
Max suf. E Field	~18 MV/m	~25 MV/m
B	7.2	4.5
Length	~3m	~2m

NC-RFQ

The NC-RFQ, which we call "bunching" RFQ, has the task to shape the CW in short bunches at the main frequency (88 MHz). The design is then optimized in order to have a longitudinal emittance as low as possible. The length of the structure is related to RF design details and it is set to 3m. The output energy is a consequence of the previous optimizations, with a further limit given by the maximum surface field, 18 MV/m (<1.8 Kilpatrick at 88 MHz). The algorithm RFQADB previously used to design the CERN Lead Ion RFQ [1] has been improved and adapted to this case.

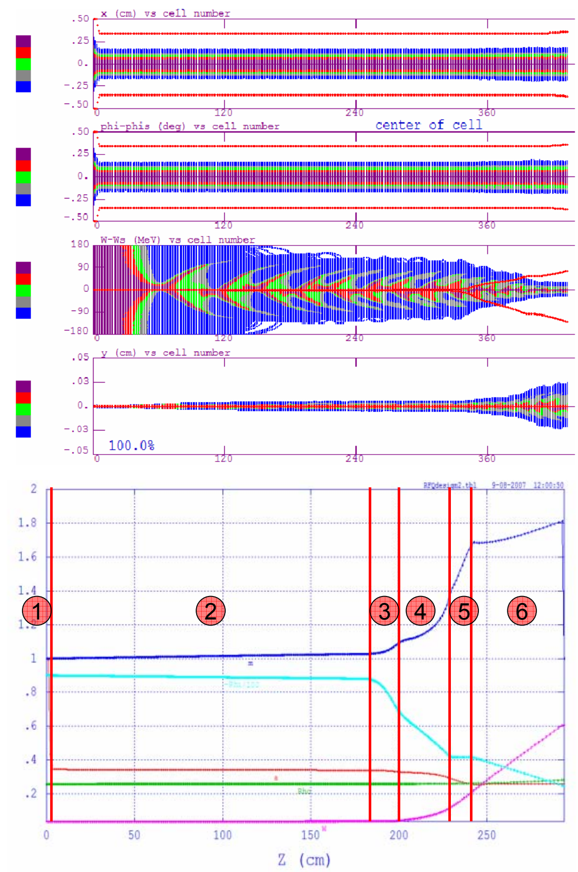

Figure 1: NC-RFQ beam dynamics simulations and main parameters along the structure. It is possible to distinguish the 6 RFQ section: (1) RMS, (2) Shaper, (3) Pre-buncher, (4) Adiabatic buncher, (5) Booster, (6) Accelerator.

Recent developments of ECR breeders show performances in terms of transverse emittance equivalent to the ones of conventional ECR ion sources. Therefore we set the nominal transverse normalized RMS emittance to 0.1 mm mrad and we have performed a study of the dependence of the output longitudinal emittance on the input transverse emittance. The results are listed in Table 2.

*The work has been carried out under the EURISOL DS Project.
http://www.eurisol.org/

Table 2: long. emittance as function of the transverse input emittance, 100k particles, 100% transmission, NC-RFQ.

t. norm. RMS (mm mrad)		longitudinal RMS	
in	out	MeV deg	mm mrad
0.100	0.100	0.065	0.094
0.150	0.151	0.068	0.098
0.200	0.201	0.072	0.104

The normal NC-RFQ was designed as a four-vane structure, by means of the HFSS code. The dissipated power per unit length (~7 kW/m) was carefully optimized. This power level allowed avoiding brazing joints between vanes and external tube: they are instead bolted and fitted to it. This solution is proposed for the SPIRAL2 driver at a higher power level [2], [3], and it is hence believed to be very reliable.

The main parameters of the 88 MHz Buncher RFQ are listed below.

Table 3: main RF parameters of the NC-RFQ.

Frequency	88 MHz
Voltage	49.7 kV
Q	18900
Mean aperture R_0	3.44 mm
Length	2.9287 m (0.83 λ)
RF power P_{RF}	23 kW
Max power density	5 W/cm^2
Current density on the joint	25 A/cm (max)

The RF power was calculated from the power P simulated by HFSS with the formula

$$P_{RF} = P\alpha_{3D}\alpha_{line}$$

with α_{3D}=1.3 for 3D details of the structure and α_{line}= 1.1 for dissipated and reflected power in the RF system.

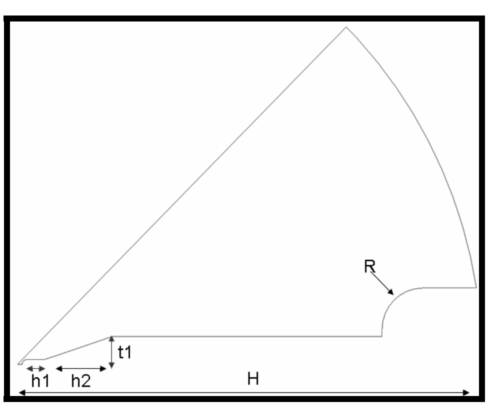

Figure 2: Transverse section of the RFQ (1/8): the quotes in figure are equal to: h1=13 mm, h2=50 mm, t1=17.42 mm, H=333 mm, R=30 mm.

The design of the end cells was accomplished too, in order to ensure a matched termination for the RFQ transmission line ($f_{end\text{-}cell} \approx f_{RFQ}$), to check the power density, as well as the current density on the joint. The results of the calculations are shown in Figure 3.

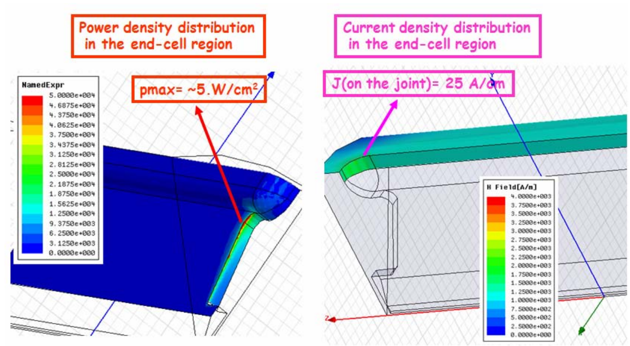

Figure 3: Power density (left) and current density (right) in the End-cell undercuts of the RFQ.

The sensitivity to perturbation of the RFQ has been investigated, with the aim of furnishing hints for mechanical tolerances. In particular the frequency variation due to a R_0 variation of 0.1 mm is equal to $\Delta f_0/\Delta R_0$=533 kHz/0.1 mm.

In order to correct for geometrical perturbations, a system of standard slug tuners can be employed, while, due to the favourable L/λ ratio (0.83), no segmentation of the RFQ is necessary. It results that for a correction of geometrical capacitance perturbation 24 tuners (two per quadrant per meter), of cylindrical shape with diameter 50 mm and average penetration of 10 mm are required.

The thermo-structural simulations of the structure were performed, by making use of the nominal RF power distribution given by HFSS and of a cooling channel arrangement similar to the one used for the SPIRAL 2 RFQ, even though a further investigation of their layout has to be made.

In Figure 4 the deformations of the structure with channel radii = 15 mm (vanes), 10 mm (bulk) water velocity = 2.5 m/s (vanes), 2 m/s (bulk) water temperature at the inlet = 20°C is shown.

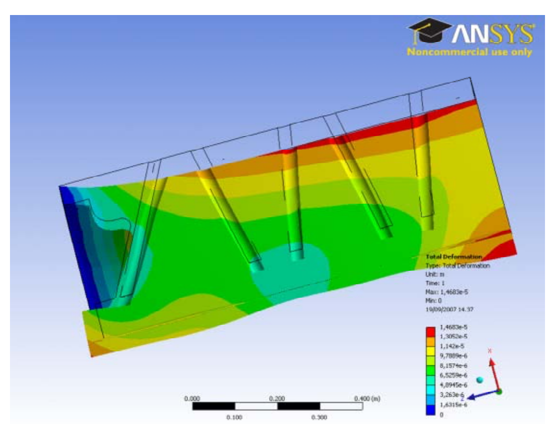

Figure 4: Thermal-induced deformation profile in the RFQ.

It has to be noticed that the maximum transverse displacement is equal to 0.014 mm ($\Delta R_{0\ max} \approx 0.014$ mm) and the maximum longitudinal displacement is equal to 0.01 mm and is located in the end-cell undercut.

SC-RFQ

The SC-RFQ has been designed to give the maximum energy gain with the limit of the maximum surface field of 27 MV/m, value given by the best Nb surface cleaning techniques available applied to the RFQ structure. Similarly to the NC-RFQ case, we have made a big effort to reduce losses and to keep emittance growths under control.

Table 4: emittance growth and transmission as function of the input transverse emittance, SC-RFQ.

t. norm (mm mrad)	growth	transm.	with an uniform longitudinal distribution, $\Delta\varphi$=15° $\Delta E/E$=5%
0.100	1%	100%	
0.150	2%	100%	
0.200	4%	99.6%	

Since we have planned not to place the SC-RFQ contiguous to the NC-RFQ due to the impossibility of a complete matching without additional focusing elements, a traditional matching line in between is needed allowing to place some diagnostics devices. A uniform, rectangular shaped ($\Delta\varphi$=15°, $\Delta E/E$=5%) distribution has been chosen as longitudinal input, which also represent the longitudinal acceptance of the SC-RFQ. Therefore the matching line should be able to give a beam with specific transverse Twiss parameters with quadrupole symmetry (no Radial Matching Section is foreseen for the SC-RFQ) and to focus the beam longitudinally at the SC-RFQ entrance.

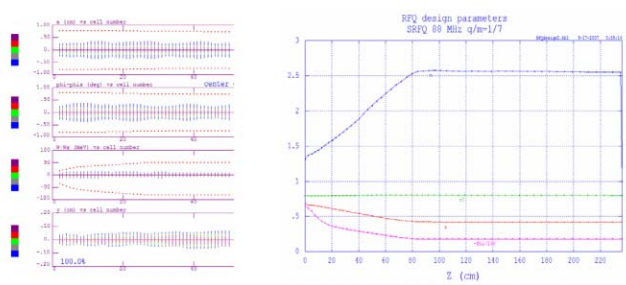

Figure 5: SC-RFQ beam dynamics simulations and main parameters along the structure.

The SC-RFQ, the geometry of which has been conservatively kept very similar to that of PIAVE [4] at INFN-LNL, was designed by means of HFSS too.

The engineering design foresees the use of a titanium stiffening cage, the role of which is to increase the frequencies of the structure mechanical modes as much as possible (beyond 120 Hz), without increasing too much the size and weight of the structure. Slow tuning is provided by mechanical deformation of the end-plates, while fast tuning, compensating for electro-mechanical resonances, is assumed to be provided by VCX systems similar to those adopted at ATLAS (ANL, USA) or PIAVE (INFN-LNL, Italy). The use of a piezo-electric system, possibly superimposed on the slow tuner mechanism, can be conceived.

Table 5: main parameters of the SC-RFQ

R_0	8 mm
r	6 mm
V_{iv}	160 kV
L	2 m (0.59 λ)
R	207 mm
f_q	88 MHz
U	1.5 J/m
C	120 pF/m
Esup	26.8 MV/m
Q_0	5×10^8
B_{max}	500 G

8.8 MHZ BUNCHING

The required 8.8 MHz bunching system should work in addition to the 88 MHz bunching process which takes place inside the NC-RFQ. The solution we have proposed is conceptually similar to the triple harmonic buncher of PIAVE, where a cavity houses the first (8.8MHz) and third (26.4 MHz) harmonics and, after a short drift, another cavity houses the second (17.6 MHz) harmonic.

The solution shown in Figure 6 offers a maximum capture limited to 80% which is slightly lowered by the longitudinal acceptance of the RFQ. Note that the longitudinal focus of the buncher should be reached close to the half of the shaper section of the NC-RFQ, which means 3 m from the buncher.

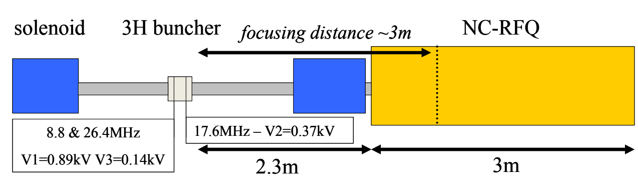

Figure 6: scheme of the last part of the LEBT including the 3H buncher.

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