PROPOSAL OF A NORMAL CONDUCTING CW-RFQ FOR THE EURISOL POST-ACCELERATOR AND A DEDICATED β-BEAM LINAC CONCEPT*

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Abstract

A combination of three superconducting RFQs has been proposed for the EURISOL post accelerator layout. At least the first RFQ of this triplet could be replaced by a normal conducting (NC) continuous wave (c.w.) device. Efficient cooling systems have been designed and already applied to existing machines at the IAP in Frankfurt. Preliminary electrode and cavity designs can be presented. Since a parallel use for β-beam applications was intended in the beginning, we have optimized the design not only for heavy ion applications with negligible beam currents at c.w. but also for lighter ions with currents up to 7.5 mA at pulsed operation. More recent investigations on β-beams came up with currents around 50 mA, which then would make a separate linac solution for β-beams necessary. We worked out some preliminary design suggestions for such a dedicated 100 MeV/u machine.

INTRODUCTION

Within the context of the EURISOL DS (European Isotope Separation On-Line Radioactive Ion Beam Facility Design Study) the applicability of superconducting linear accelerator structures are verified on the basis of experiences that have been done e.g. at GANIL [1] and the INFN [2]. A super conducting 88 MHz SRFQ triplet (fig. 1) is preliminarily scheduled for the post accelerator section with output energy of 670 keV/u. In parallel we have developed a normal conducting NC-RFQ solution to compare both concepts.

A challenging feature of the EURISOL post-accelerator is the required simultaneous usability for β-beam applications. While the EURISOL task asks for acceleration of rare isotope beams (RIBs) with mass to charge ratios of A/q ≤ 9.52 at c.w. with almost no beam current, β-beams use $^{6}He^{2+}$ or $^{18}Ne^{10+}$ with an A/q ≤ 3 and peak currents of 7.5 mA and 50 mA respectively on the basis of more recent investigations. The duty cycle here is very low with only 0.05% (50 µs with 10 Hz repetition rate). An important problem with combining both tasks at a NC-RFQ is the electrode voltage, which has to be kept down at c.w. operation in order to preserve a moderate power load of the structure. On the other hand there is a need for stronger focusing with increasing beam currents, which becomes more and more important especially with lighter ions.

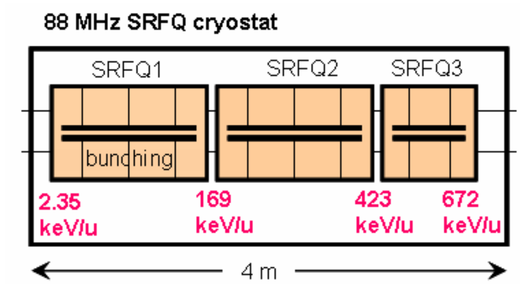

Figure 1: Proposed SRFQ-sequence.

A NC-RFQ AS AN ALTERNATIVE FOR SRFQ1

The main parameters are listed in table 1. We chose a quite moderate electrode voltage of only 60 kV, which would result in a power consumption of approximately 82 kW. The electrode design is shown in fig. 2 where characteristic parameters like aperture, modulation, ideal phase, longitudinal and transversal phase advance are plotted against cell number. The input distribution has been chosen on the basis of the EURISOL design report, it is of the waterbag type with an rms-emittance of $\varepsilon_{rms,n}$ = 0.1 mm mrad including 100% of the particles. The design is optimized for two exemplary ion beams, one with an A/q = 9.52 at "zero" current for the EURISOL task and the other one is a $^{6}He^{2+}$-beam at 7.5 mA, representing the β-beam requirements. Space charge calculations have been executed by using a particle in cell method following the principle of "charged rings". We have decided to use 10^3 macro particles, which has been proven to be a very good compromise between calculation time and reliable results for preliminary calculations. Final designs are always checked with much higher numbers of particles. Simulation results are also presented in table 1, all data are valid for 100% of the particles.

For the cavity design we could imagine to use an IH-resonator [3], the conventional 4-rod type [4] or probably a 4-vane type with coupling windows [5]. There is a very efficient cooling system already in existence for 4-rod structures [6], which provides c.w. operation, while there would have to be some new developments with the IH-RFQ.

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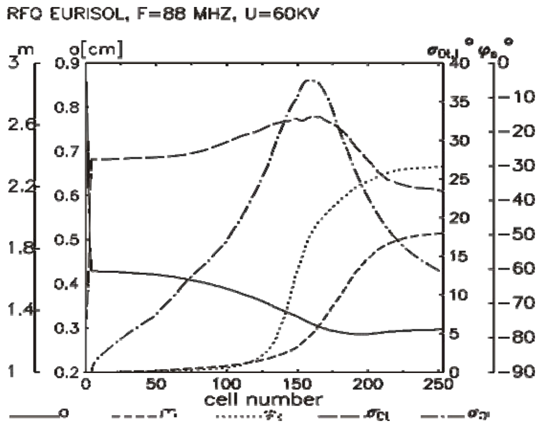

Figure 2: The NC-RFQ electrode design. Plotted are aperture, modulation, ideal phase and phase advances against cell number.

Table 1: Main RFQ design and beam parameters

length l	245 cm	
frequency f_0	88 MHz	
mass to charge ratio m/q	≤9.52	
input energy W_{in}	2.35 keV/u	
output energy W_{out}	167 keV/u	
aperture a	0.43 cm	
electrode voltage V_{el}	60 kV	
RF-power consumption P_{RF}	82 kW	
duty cycle	100%	
input emittance rms normalized	0.1 mm mrad	
transmission T (0 mA/7.5 mA)	100%	97.9%
transval emittance growth $\Delta\varepsilon_t$ (0 mA/7.5 mA)	4%	8.5%
energy spread ΔW (0 mA/7.5 mA)	1.5%	2.5%
phase width Δφ (0 mA/7.5 mA)	±17°	±22.8°

A NC-RFQ TANDEM AS AN ALTERNATIVE FOR SRFQ1,2&3

The concept of the above NC-RFQ could be extended to replace the complete SRFQ triplet. The whole NC-RFQ section would become about 10 m long to reach a final energy of 460 keV/u and to fulfill the EURISOL and the β-beam requirements. For several reasons it is necessary to divide cavities that become longer than about 4 m. One of the reasons for that is the tuning of the field on the electrodes, which becomes more complicated with increasing the length of the structures [6]. There are several examples for RFQ combinations already in existence, e.g. at the MPI in Heidelberg [7] or at the HMI in Berlin [8].

NC-RFQ1 for EURISOL would be quite the same as the one presented above in fig. 2, with the exception of the accelerating part, which becomes about 1.5 m longer with a special section at the end to match the beam to the following NC-RFQ2 (fig. 3). There are no additional transport elements between the RFQs; the gap between the electrodes is 1.7 cm.

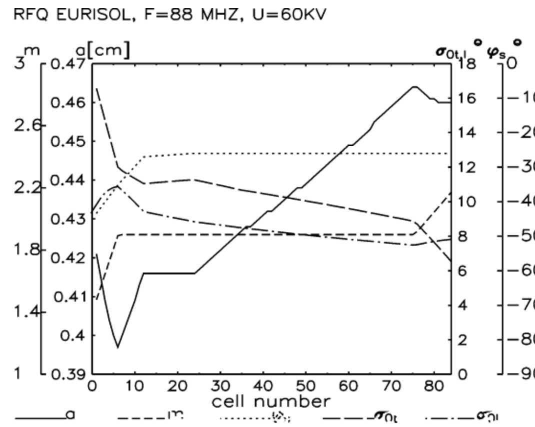

Figure 3: The NC-RFQ2 electrode design.

Table 2: Parameters of the NC-RFQ tandem

	NC-RFQ1		NC-RFQ2	
l	387 cm		395 cm	
f_0	88 MHz		88 MHz	
m/q	≤9.52		≤9.52	
W_{in}	2.35 keV/u		260 keV/u	
W_{out}	260 keV/u		460 keV/u	
a	0.43 cm		0.43 cm	
V_{el}	60 kV		60 kV	
P_{RF}	131 kW		131 kW	
duty cycle	100%		100%	
$\varepsilon_{rms,n}$ input	0.1 mm mrad		0.104 mm mrad	
T (0 mA/7.5 mA)	100%	97.9%	99.8%	94.4%
$\Delta\varepsilon_t$ (0 mA/7.5 mA)	4%	9%	0%	1.5%
ΔW (0 mA/7.5 mA)	1.2%	2.5%	1%	2%
Δφ (0 mA/7.5 mA)	±17°	±23°	±15°	±18°

A DEDICATED β-BEAM LINAC CONCEPT

Due to the low duty cycle of 0.05% and the high pulse beam current of 50 mA it seems to be reasonable to use normal conducting NC-RF-structures instead of superconducting cavities even up to the final energy of 100 MeV/u. Using accelerating gradients between 3 and 6 MV/m this leads to very small thermal loads.

Some preliminary design calculations have been executed for a possible normal conducting RFQ solution; main parameters are listed in Table 3. Due to the resonance frequency of 176 MHz we would suggest to use a 4-rod type structure [4]. Possible candidates for NC-DTLs are H-mode cavities (IH-, CH-DTL). In general, H-mode cavities have a high shunt impedance. IH-structures are operated in the low energy regime between 0.1 MeV/u and 10 MeV/u with RF-frequencies between 36 and 250 MHz. Figure 4 shows the effective shunt impedance (including the synchronous phase) as function of the particle β = v/c. The IH structure has no competitor with respect to RF-efficiency. The horizontal bars are representing existing IH structures. Additionally, high gradients of up to 10.7 MV/m have been achieved in pulsed operation [9].

The use of the KONUS beam dynamics [10] leads to less RF-defocusing and long lens free sections and therefore to high real estate gradients. The first DTL part could consist of three IH-structures operated at 176 MHz. The input energy is 1 MeV/u and the output energy 8 MeV/u. The total voltage gain is 22 MV with a length of about 7 m. The total required power per cavity including the beam loading is between 600 and 750 kW.

Table 3: A possible NC-RFQ concept for β-beam application

length l	275 cm
frequency f_0	176 MHz
mass to charge ratio m/q	≤3
input energy W_{in}	8 keV/u
output energy W_{out}	1 MeV/u
electrode voltage V_{el}	95 kV
input emittance total	50 mm mrad
transmission T (50 mA)	97%

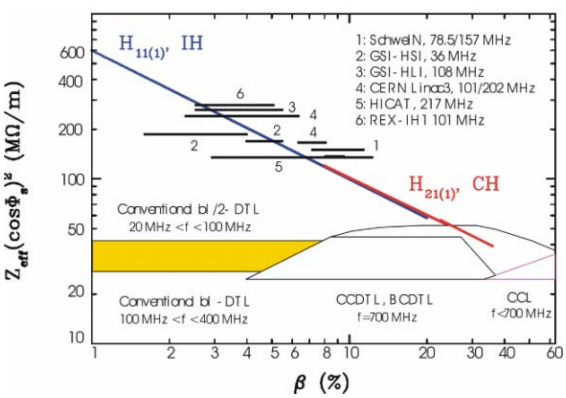

Figure 4: Effective shunt impedance of different RF-structures as function of β = v/c. The horizontal bars are representing existing IH-structures.

The following DTL section from 8 MeV/u to 100 MeV/u could consist of NC-CH-cavities. CH-cavities are operated in the H_{21}-mode. The CH-section would be operated at 352 MHz. For this frequency cost efficient klystrons in the MW-range are available. To cover the voltage gain of 276 MV about 46 CH-structures are necessary. The effective voltage per cavity varies between 5 and 7 MV. The total power per cavity is kept below 1 MW including the beam loading. The length of the CH-DTL is about 100 m. Figure 5 shows a prototype of a NC-CH cavity which is being developed for the new proton injector for FAIR [10]. This 70 MeV, 70 mA p-linac will use 11 NC-CH-structures. Figure 6 shows the schematic layout of a possible H-mode linac for β-beam applications. The total length is about 110 m. This corresponds to a real estate gradient of 2.73 MV/m.

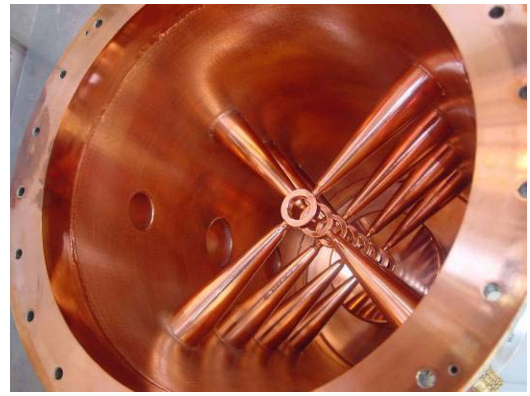

Figure 5: 350 MHz CH-prototype cavity.

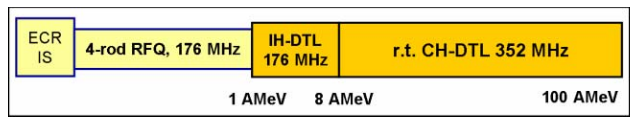

Figure 6: Schematic layout of an IH/CH-DTL for the production of β-beams.

CONCLUSIONS

Some preliminary design suggestions of normal conduction RFQ alternatives have been evolved for the EURISOL design study. Furthermore we can present a possible design for a dedicated β-beam linac that could be a basis for continuative discussions within the community.

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