Studies of a Superconducting RFQ for Legnaro.

G. Bisoffi, A. Lombardi and A. Pisent
INFN-Laboratori Nazionali di Legnaro, via Romea 4 I-35020 Legnaro (Padova) Italy;
V. A. Andreev
Institute for Theoretical and Experimental Physics
Bolshaja Cherjomushkinskaja 25, 117259 Moscow, Russia.

Abstract

The development of a superconducting radio frequency quadrupole, carried out at the L.N.L., is described. The resonator is a prototype for the construction of a new injector of the linac ALPI, at present in commissioning phase, and it will follow an ECR source and a buncher located on a 350 kV platform.

The main goal is to test a second generation prototype with a $^{58}Ni^{8+}$ beam, accelerating it from β_{in}=0.043 to β_{out}=0.046. The injection velocity is reachable using the Legnaro XTU-tandem at its minimum terminal voltage of 8 MV. The chosen frequency, 80 MHz, is the same as that of ALPI low-energy cavities and allows for longitudinal matching. A four-cell structure, as in the Stony Brook case, and a non conventional modulation factor m=3, providing good acceleration with the proper transverse focusing and the electrode size, were opted for. These constraints impose a value a=19.3 mm for the minimum aperture radius if the maximum ratio $E_a/E_S \approx 1/7$ is looked for.

Reasonable compromise among several requirements, such as high shunt impedance, efficient removal of dissipated power by liquid helium , the need to keep surface magnetic field below the SC material critical value, to avoid helium gas bubbles to be trapped in electrodes and supports and to avoid resonant response to mechanical vibrations, gave rise to a variety of possible support geometries. The radio frequency features have been investigated with the code M.A.F.I.A. and the most promising structures further studied with a series of measurements on aluminum models. Results of computer simulations and room temperature measurements are shown.

INTRODUCTION

In the framework of the superconducting post accelerator project named ALPI [1], now in commissioning phase at the Laboratori Nazionali di Legnaro (L.N.L.), the necessity of a positive ion injector rose up, so as to increase the range of the available beams toward the very high masses with respect to the present negative ion injector followed by a XTU-tandem.

The proposed scheme for a new injector contains an ECR source [2], placed on a 350 kV platform, followed by a chain of superconducting RFQ resonators [3].

The new accelerating structure will cover the velocity range from β=0.01 to β=0.05 for all ion species up to uranium with a minimum charge-over-mass ratio of $\approx 1/8.5$. The velocity range is dictated by the maximum available voltage of the platform on one side and by the injection energy of ALPI on the other.

The first step in the design of the superconducting RFQ chain was to study and construct models for the second generation prototype of one of the resonators [4].

In order to thoroughly test the accelerator prototype we decided to design and build a resonator that can accelerate a beam coming from the L.N.L. tandem with a reasonably low β. A suitable beam is $^{58}Ni^{8+}$ with a tandem terminal voltage of 8 MV (β_{in}=0.04).

The resonant frequency of the prototype has been chosen, accordingly with the ALPI accelerator, to be 80 MHz.

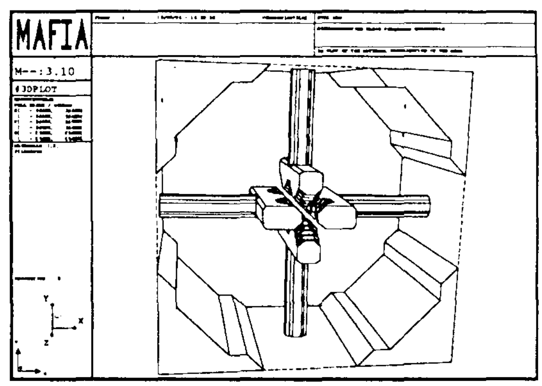

Figure 1: SRFQ Single Stem Resonator in a M.A.F.I.A. Simulation

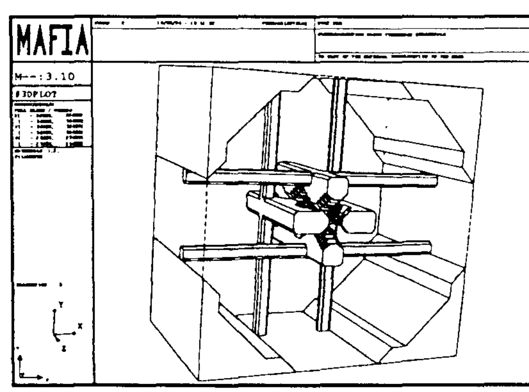

Figure 2: SRFQ Double Stem Resonator in a M.A.F.I.A. Simulation

TABLE 2
Comparison of Computed and measured RF parameters for RFQ structures suitable for the superconducting accelerators.

	Single Stem		Double Stem		
	M.A.F.I.A.	Measured	M.A.F.I.A.	Measured	
Resonant Frequency	85.03	86.287	85.1	85.200	MHz
Q	13.500 (Cu)	2.425	13.000 (Cu)	1.928	10^3
Stored Energy	2.58	—-	3.13	—-	J
$B_{sup.max}$	242.	—-	74	—-	Gauss
Capacitance	100.1	(*)	134.3	(*)	pF/m
Max Dipole Component	0.0	6.5	0.0	4.2	%
R_{sh}	505.	94. (*)	361.	63.(*)	kΩ·m
$(R_{sh})_{eff}$	—-	497. (**)	—-	474. (**)	kΩ·m

* An estimated value of the capacitance of 118. pF/m was used to calculate the shunt impedance
** The $(R_{sh})_{eff}$ is computed scaling the R_{sh} with the theoretical Q value

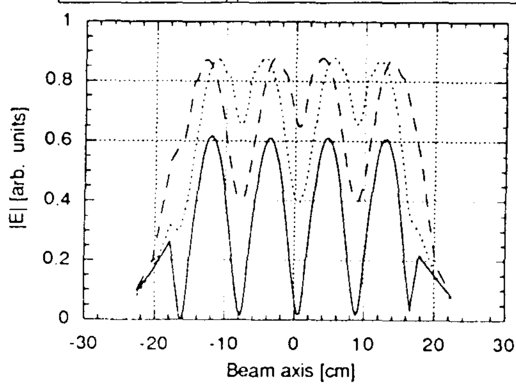

Figure 3: M.A.F.I.A. |E-field| Distribution for the Single Stem structure (solid line beam axis, dashed line x=10 mm, dotted line y=10 mm)

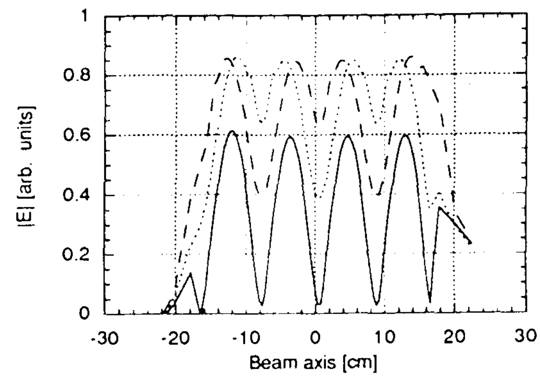

Figure 5: M.A.F.I.A. |E-field| Distribution for the Double Stem Structure (solid line beam axis, dashed line x=10 mm, dotted line y=10 mm)

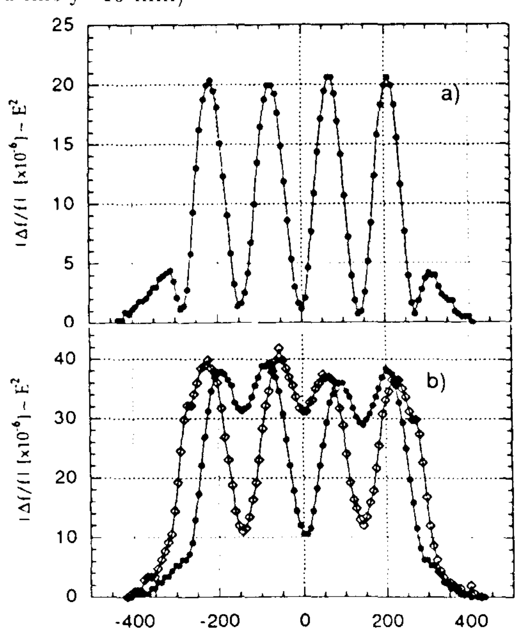

Figure 4: Measured E^2-field Distribution for the Single Stem structure: a) on axis, b) diamond x=10 mm, solid circle y=10 mm

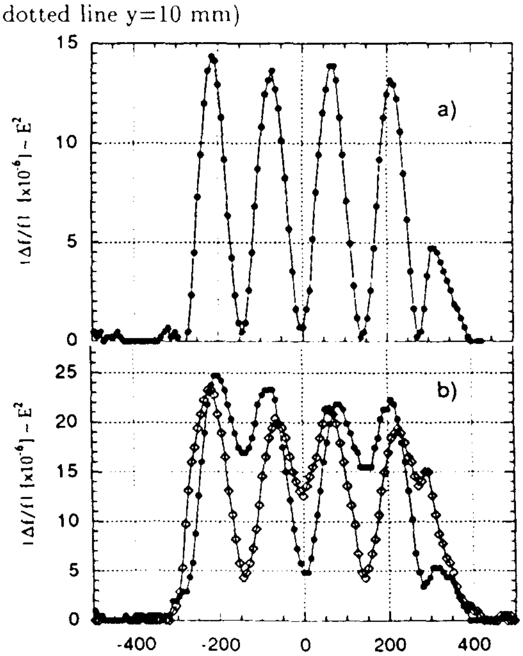

Figure 6: Measured E^2-field Distribution for the Double Stem structure: a) on axis, b) diamond x=10 mm, solid circle y=10 mm

Beam Dynamics Parameters

At the present stage of the project the beam analysis of the whole injector is still under investigation. The prototype has been simulated as a stand alone structure using, as input, a bunched beam with the normalized transverse emittance of E_n=.5 π mm mrad and, in the longitudinal phase plane, $\Delta\varphi_{in}$=10° (at 80 MHz), ΔW_{in}=35 keV.

TABLE 1
SRFQ Parameters

Input Energy	874.	keV/u
Output Energy	987.	keV/u
Intervane Voltage	424.	kV
Electrodes length	333.	mm
φ_s	-25.	deg
Aperture (a)	19.3	mm
Modulation (m)	3.	

The structure is $2\beta\lambda$ long for 4 accelerating cells. The design philosophy is to maximize the accelerating field [3] keeping the maximum surface electric field constant. The result is an unusually large modulation factor and a large aperture. The design parameters for the prototype are summarized in table 1.

RF Structures

The tests performed so far were devoted to check M.A.F.I.A. simulations on two possible structures suitable for our purposes. The structures, built around the same set of electrodes defined by the desired beam dynamics, are low power models made out of aluminum. In both cases we chose "four-rod" structures, to cope with the relatively low operational frequency, but the electrodes are "vane-like", as shown in figures 1 and 2.

The main difference between them is that, in the first one, the electrodes are supported by a single stem located at the centre of the resonator while, in the second one, two stems support the electrodes off centre and connect them to opposite sides of the outer tank. The first one is appealing for the higher degree of symmetry (electrodes supported in their barycenter) and for the higher value of the shunt impedance. The second one would be mechanically more stable and allow an easier cooling by liquid helium in hollowed supports (by far the most dissipative region in both structures) and the maximum magnetic field value is lower.

The outer tank has the same dimensions in both structures (ϕ_{est}=729. mm)

Using the "bead pulling" technique the E-field distribution was measured in both models: five scans were done for each of them, on the axis of the structure and ±10 mm off axis on the horizontal and vertical directions (refer to fig.1 and fig. 2).

Figures 4 and 6 show the results on the axis and at +10 mm on x and y for the two structures.

The on-axis plot shows the accelerating E-field pattern with the four cells of the structures. The off-axis ones clearly show the effect of the strong modulation giving a higher field where the electrodes are closer to the axis and a considerably lower field $\beta\lambda/2$ apart along the beam direction. The two small peaks due to the modulation of the electrodes can be noticed at the entrance and exit gaps.

The differences between the two structures, put in evidence by both simulations and experiments, reflect the different the shape and position of the supports. The asymmetric supports of the "double stem"structure have only the effect of unbalancing the field strength on the entrance and the exit gaps: the field is higher on the side of the vertical electrodes supports.

The effect of the fringe field gaps on the beam dynamics has still to be analyzed.

In Table 2 the main computed and measured rf parameters of the two structures are summarized.

Conclusions

The study on the SRFQ structures for the L.N.L. positive ion injector is proceeding. Two structures have been simulated and modelled in order to check the rf performances of such resonators. From this point of view both are suitable for the superconducting prototype and a thorough study of both cryogenic specifications and mechanical stability, the next step to come, will be probably decisive for the final choice.

Acknowlegments

The authors are very grateful to the L.N.L. machine shop staff, particularly to M. Lollo and S. Marigo, for their help and quickness in preparing the models. We would like to thank also L. Boscagli and D. Carlucci for their help during the measurements.

References

[1] L. Badan et al., "Review of ALPI", to be published into the proceedings of EPAC 1994, London.

[2] M. Cavenago and G. Bisoffi, "Commissioning of the ECR ion Source Alice", NIM A328(1993), 262-265.

[3] I Ben-Zvi, a. Lombardi and P. Paul, "Design of a Superconducting RFQ resonator", Particle Accelerators **35** (1991), 177.

[4] A. Jain et al., "Fabrication and test of a Superconducting RFQ.", NIM A328 (1993) 251-254.