Status of the SUNY Superconducting RFQ[1]

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Abstract

A RFQ resonator is presently being developed at SUNY. This resonator is a prototype for a chain of six short ($\sim$ 0.5m long), superconducting (Pb plated Cu), 50 MHz resonators designed to accelerate beam from β = 0.01 to 0.05. The chain accepts a pre-bunched beam to save on superconducting length. The resonators are of four-rods type with vane-like electrodes. The prototype resonator is designed to accelerate ions of $q/A = 1/6$ from $\beta = 0.030$ to 0.036, operating at a peak surface electric field of 16 MV/m. The electrodes have a rather high modulation parameter of 4 and a wide aperture of 1.57 cm radius. These values are chosen to maximize the accelerating field (E_a) for a given peak surface electric field (E_s). At the design value of E_s= 16 MV/m, the resonator is estimated to have E_a= 2.0 MV/m, stored energy of 4 J, peak surface magnetic field of 360 Gauss, and inter-vane voltage of 0.42 MV. Results of RF tests on this prototype resonator will be presented.

I. INTRODUCTION

The superconducting RFQ has been proposed for the acceleration of low velocity heavy ion beams [1]. It combines the focusing and acceleration efficiency of the RFQ structure with the low power CW operation of a superconducting device. For this particular application a new design procedure has been developed [2] which optimizes the ratio between the accelerating electric field and the maximum surface electric field. This optimization leads to a linear dependence of the minimum aperture (a) on β, for a given modulation factor (m). With this variation of a, a voltage tapering is needed in order to keep the maximum surface field constant along the structure. The voltage tapering requirement and the need of low stored energy for superconducting operation suggested the short RFQ (RFQlet) design [2]. Additional advantages of RFQlets are a wide transit time curve and possibility of independant phasing of resonators. These factors give more design flexibility to satisfy beam dynamics requirements.

An accelerating chain going from β = 0.01 to β = 0.05 has been designed using the superconducting RFQlets. It consists of six resonators operating at a resonant frequency of 50 MHz which accelerate positive heavy ion beams, with $q/A \approx 1/6$. Such beams can be delivered by an ECR source on a high voltage platform ($\sim$ 300 KV). A peak surface electric field of 16 MV/m (for Pb plated resonators) was assumed in this design. One of the resonators in this chain has been built as a prototype. This paper describes the present status of this prototype resonator.

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II. THE PROTOTYPE RESONATOR

The prototype resonator is the third element in the chain described above. It has only four cells and an input β of 0.03. This β is suitable for beam tests using a beam delivered by the SUNY tandem Van-de-Graaff.

For a low operating frequency of 50 MHz, we have chosen the four rods RFQ structure [3]. This is an open structure consisting of four electrodes connected in pairs, via supports, with a common base plate. However, the electrodes in the present design have a 'vane-like' transverse section which is necessary for a large modulation (m=4) and which minimizes the high order multipole components. The electrical properties of a short structure of this type can be studied using an equivalent L-C circuit. The capacitance of the circuit is contributed by the electrodes (most significant term), by the beam ports and by the supports. The inductance is concentrated in the supports. Using this simple model [2,4] we have been able to obtain reasonable estimates of the frequency, unloaded Q, stored energy, peak surface magnetic field and voltage unbalance of the resonator. Some of these results are given below.

Figure 1 shows a schematic view of the resonator. This resonator is made out of copper and will be lead plated on the internal surfaces and cooled to liquid helium temperature for superconducting operation. The surfaces which have a high power density are cooled by direct contact with liquid helium. These include the electrodes and their supports. The external tank, in the shape of a can open on its bottom, is cooled by conduction. The connection of the resonator to the cryostat's liquid helium tank is made via a shallow helium manifold on top of the resonator.

The electrodes are hollow in order to reduce weight and to provide a channel for the liquid helium. Each pair of opposing electrodes (which have the same polarity) is connected to a hollow sphere using two curved tubes about 4 cm in diameter . The 12 cm diameter spheres are then connected to the top plate via 8 cm diameter straight tubes. These tubes act as supports for the electrodes as well as liquid helium channels.

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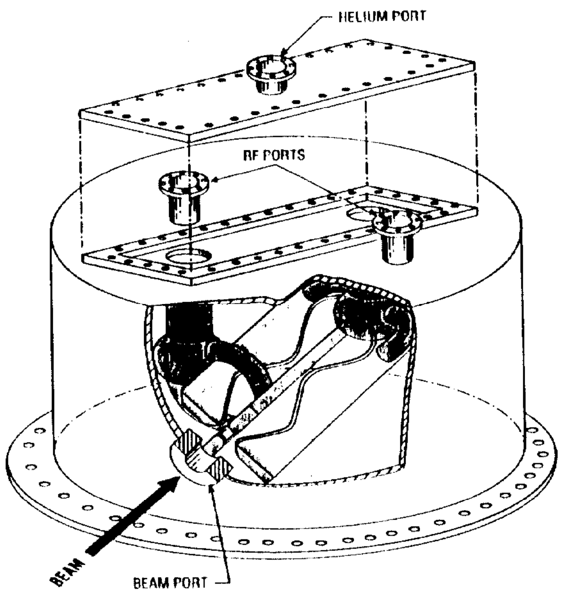

Figure 1: *A schematic view of the prototype superconducting RFQ resonator*

The rf ports for the input coupler and pick-up are located on the top, next to the helium manifold.

The can shaped outer conductor is closed at the bottom using a copper plate which is attached to a flange on the can. An indium seal is used to provide a good electrical contact.

The external tank has been manufactured by a combination of spinning and TIG welding techniques. The 9.5 mm thick top is spun from an OFHC copper plate in order to avoid a joint in the corner. The side wall is made by rolling and welding a 4.8 mm thick copper sheet. The flange for the bottom plate is then spun. The tank dimensions are 53 cm outer diameter and 60 cm high.

The electrodes have been machined from solid copper blocks. The profiles of the electrodes, as determined by beam dynamics calculations, have been machined on a 3-D CNC milling machine. The electrodes are 3.8 cm thick and have a constant transverse radius of curvature. Then the electrodes have been hollowed out and fitted with covers. All the corners have been rounded with a radius of curvature of $\sim$ 5 mm to reduce the surface electric fields.

The two connecting spheres have been manufactured by spinning of half spheres from OFHC copper plates. The half spheres have been machined, joined to form the spheres, then machined again to provide the necessary penetrations.

The tubes connecting a pair of electrodes to the sphere have been made out of curved 55° elbows with straight tube extensions on both ends.

The main construction technique used to assemble the resonator from these components is furnace brazing. The exceptions are the joints between the two half spheres and the straight tube extensions of the elbows which were done by electron beam welding. The brazing has been done in three stages. The first braze joins the electrode covers to the vane electrodes. In the second brazing stage a pair of electrodes, a pair of curved connecting tubes, a sphere and a support tube, are joined together to form an electrode assembly. Two electrode assemblies are needed. In the final brazing stage the two electrode assemblies, outer conductor, two beam ports, two rf ports and helium manifold are joined to result in the complete resonator.

Two different brazing alloys have been used. The first two brazing stages were done using a 795°C melting point alloy at slightly different temperatures. The final braze has been done with a 705°C alloy.

III. RF TESTS

Measurements of the electrical characteristics of the prototype resonator have been carried out at Grumman Corporation using the bead pull technique. The electrical energy density distribution measured along the axis of the structure is shown in Figure 2. The four central peaks correspond to the four RFQ cells. The peaks on both ends are due to the fringe fields in the region between the electrodes and the beam ports. It is seen that for such short structures, the fringe fields make a non-negligible contribution to the total acceleration. The progressive decrease in the peak fields of the cells is a result of increase in cell length. We observe an asymmetry in the strengths of the fringe fields at the two ends. The reason for this asymmetry is not clear, however, it is also seen (Figure 2) in a numerical simulation of the cavity using the MAFIA codes [5].

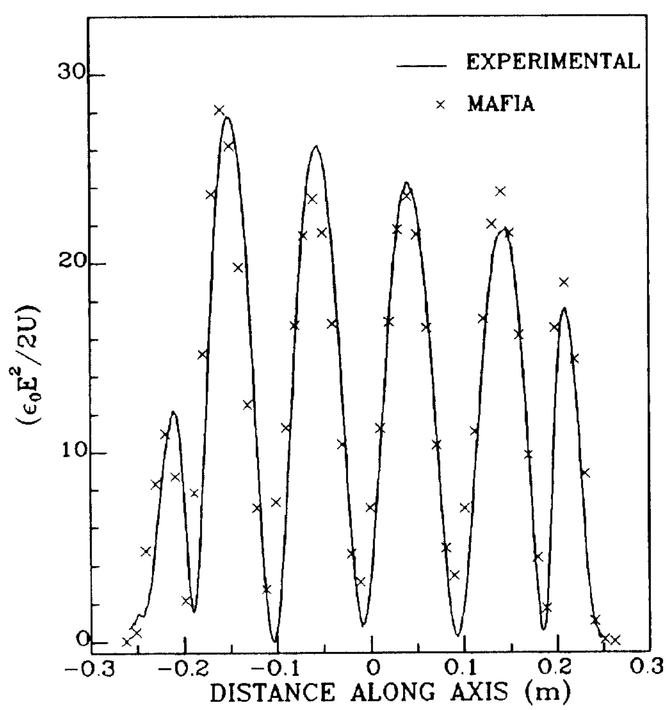

Figure 2: *Electrical energy distribution along the axis.*

Electrical characteristics such as the resonant frequency (f), stored energy (U), capacitance (C), peak surface electric (E_s) and magnetic (B_s) fields, etc. are obtained from the bead pull measurements. Table 1 summarizes the results. Values of these characteristics obtained from MAFIA, as well as approximate analytical estimates, are also given for comparison. A detailed discussion of the table can be found in reference [6].

Table 1. MAFIA Results vs Measurements and Approximate Expressions

Characteristic	MAFIA	Approx.	Measure.
f (MHz)	56.493	63.3	57.372
Q	10400	8370	7200
C_{total} (pF)	41	45	53
U(J)	3.6	3.9	4.7
Γ (Ω)	20.2	17.2	14.1
E_s^2/U ($[MV/m]^2/J$)	72	62	40
E_a^2/U($[MV/m]^2/J$)	1.1	1.0	1.1
E_a/E_s	0.12	0.13	0.17
B_s^2/U (G^2/J)	7.4×10^4	3.3×10^4	3.0×10^4
$\Delta V/V$(%)			
Ends	4.0	3.8	——
Centre	0.94	3.8	——

The measured, or computed, axial electric field of the structure can be used to compute the transit time factor (TTF). As pointed out earlier, the fringe field contribution must be included in the calculation, since it provides $\sim$ 20% of the total energy gain. Figure 3 shows the TTF curves computed from the MAFIA simulation and an approximate analytical model. The approximate model uses a two terms Fourier-Bessel expansion for the regular cells and a fringe field term similar to that developed by Crandall [7]. We note that the agreement between the various TTF curves is satisfactory. For comparison, we also show the TTF computed with only the two term potential function, neglecting the fringe region. The shift in the peak position is due to switching off the acceleration in the fringe field. Also, the TTF curve is narrower when fringe field is included.

IV. CONCLUSIONS

A prototype of a superconducting RFQ is presently being tested at SUNY. Preliminary field measurements have been done and found in good agreement with numerical simulations. Off axis bead pull measurements will be done to get the multipole content of the field in the beam region. This is particularly important in view of the high modulation factor ($m = 4$) and the small transverse radius of curvature ($\rho/r_0 = 0.5$).

The next steps in the testing program are lead plating and superconducting tests. Plating will be done using the resonator's outer conductor as a plating vessel. We have done plating experiments on a model to determine the anode shape. The model used had the full transverse dimensions and half the length of the actual resonator. The uniformity of the plating was within 15% using a very simple anode shape. To obtain this result the plating current density had to be adjusted to 0.5 mA/cm^2.

Off line tests will examine issues such as the multipactoring levels, Q vs field performance and sensitivity to accoustical vibrations.

Beam tests of the cavity, using a beam from the SUNY tandem Van de Graaff are planned in order to study the performance of the RFQlet under realistic conditions.

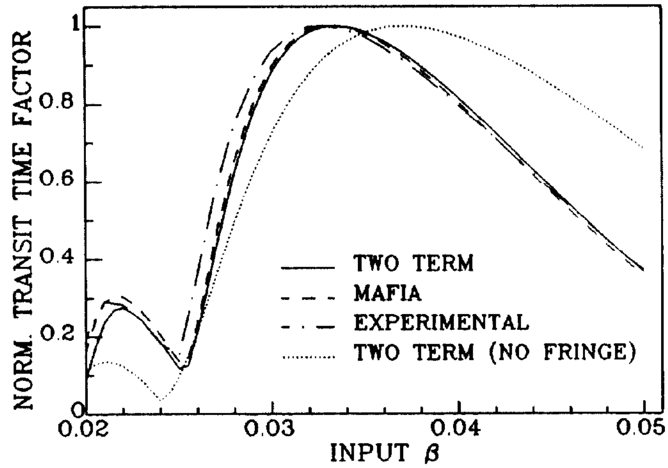

Figure 3: *TTF curves computed from various electric field distributions at* f = 56.493 *MHz.*

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VI. REFERENCES

1. Ilan Ben-Zvi, *A Superconducting RFQ for an ECR Injector,* Particle Accelerators,**23**,265 (1988)
2. I. Ben-Zvi, A. Lombardi and P. Paul, *Design of a Superconducting RFQ Resonator*, Particle Accelerators (in press).
3. A. Schempp, M. Ferch and H. Klein, *Proc. 1987 Particle Accelerator Conference* in *IEEE Trans. Nucl. Sci* **87CH2387-9**, 267(1987).
4. I. Ben-Zvi, A. Jain, H. Wang, and A. Lombardi, *Electrical Characteristics of a Short RFQ Resonator, Proc. 1990 Linear Accelerator Conf., September 10-14, 1990, Albuquerque, NM, pp. 73-75*
5. *MAFIA User Guide*, The Mafia Collaboration, DESY, LANL and KFA, 1988.
6. H. Wang, I. Ben-Zvi, A. Jain, P. Paul and A. Lombardi, *Numerical Simulations of a Short RFQ Resonator Using the MAFIA Codes, these proceedings*
7. K. R. Crandall, Private Comunication