Construction of a Superconducting RFQ Structure

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Abstract

This paper reports the design and construction status of a niobium superconducting RFQ operating at 194 MHz. The structure is of the rod and post type, novel in that each of four rods is supported by two posts oriented radially with respect to the beam axis. Although the geometry has four-fold rotation symmetry, the dipole-quadrupole mode splitting is large, giving good mechanical tolerances. The simplicity of the geometry enables designing for good mechanical stability while minimizing tooling costs for fabrication with niobium. Design details of a prototype niobium resonator, results of measurements on room temperature models, and construction status are discussed.

I. INTRODUCTION

Although cw electric fields exceeding 100 MV/m have been achieved in a superconducting niobium RFQ structure, the structure tested had vanes only 6.5 cm long, and was not suitable for accelerating beam [1]. The RFQ design presented here is intended as a next development step [2,3] for the niobium short-vane RFQ with the following objectives:
1. See if high accelerating fields can be obtained in a superconducting RFQ structure of useful length (50 cm).
2. Permit testing with beam at the ATLAS heavy-ion facility.
3. Exhibit sufficient mechanical stability for cost-effective operation in low-beam-current applications.

The potential for testing with an ATLAS heavy-ion beam provides considerable flexibility [6]. The velocity profile, and the vane modulation, can be specified without knowing precisely what electric field gradients can be achieved, since the charge-to-mass ratio Q/A of a test beam can be varied over a substantial range, from 1/10 to 1/2. A test area is available in which a bunched beam of velocity as low as .02 c can be made available. To permit such testing, the entrance velocity of the structure is chosen to be 0.02 c, and the operating frequency to be the 16th harmonic of the ATLAS bunching frequency, or 194 MHz.

II. RESONATOR DESIGN

A. General Characteristics

Figure 1 shows the resonator geometry. Although the structure has four-fold rotational symmetry the dipole-quadrupole mode separation is large, yielding good mechanical tolerances. The mode separation results from the large electric-field coupling between the longitudinal rods or vanes, the inductive coupling between the radial posts being relatively weak in this geometry.

The four-fold symmetric rod and post geometry has several advantages for construction of a superconducting niobium RFQ:
1. The large mechanical tolerances are compatible with the need to heavily chemically polish the niobium surface, with resulting uncertainties of tens of microns in the final position of the interior cavity surfaces.
2. The cost of tooling and fabricating in niobium are minimized by the simplicity of the structure, which can be formed by joining eight simple "T" sections.
3. Since peak surface field, rather than shunt impedance, is the primary design constraint for superconducting niobium structures, the rod and post structure can assume massive proportions, providing excellent mechanical stability.

B. Mechanical Features

The resonant cavity, fabricated of niobium, is jacketed in a stainless steel housing which forms a liquid helium container through which pass beam ports and rf coupling ports which access the resonator interior. This design permits operation with a common beam and cryogenic vacuum system (characteristic of the ATLAS accelerator) while avoiding the use of copper-niobium composite material. The rod and post structures will be formed of 1/8 inch niobium sheet, and the resonator cylindrical wall of 3/16 inch material.

C. Vane Modulation

The vane modulation is chosen so that if surface fields as high as were obtained in the earlier short vane tests can be attained in the larger structure, a $^{238}U^{24+}$ beam will be matched. If the structure proves limited to lower surface fields, it will still match beams of higher Q/A, so that a beam test at ATLAS would be possible for a range of possible accelerating gradients.

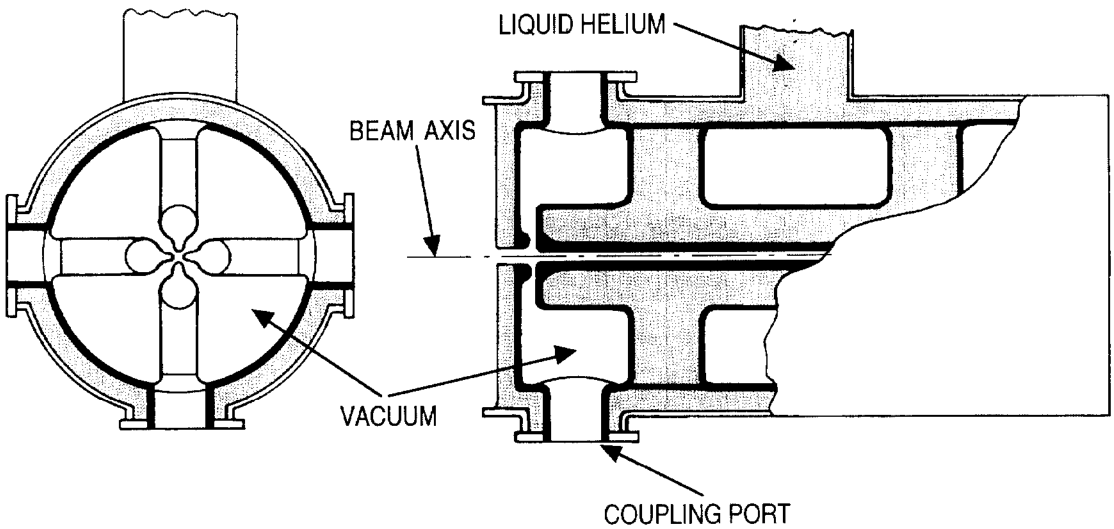

Figure 1 - End-section and cut-away view of the four-fold symmetric superconducting RFQ. The operating frequency is 194 MHz, and the active length 46.6 cm. The resonant cavity will be formed of niobium, then housed in a stainless steel outer jacket which serves as a liquid helium container. For details, see the text.

For the vane design, we assume the upper limit of possible performance for a superconducting structure to be a peak surface electric field of 120 MV/m. To match possible test beams from the ATLAS accelerator, we also assume the following parameters:

Frequency	194 MHz
Entrance velocity	β_0 = 0.02
Transverse Emittance	ϵ_x = 10 π mm-mrad
Longitudinal Emittance	ϵ_z = 40 π KeV-nsec

The design chosen calls for the vanes to be formed of niobium plate with a constant (transverse) thickness of 7.65 mm. The vane modulation is chosen to yield as high an accelerating gradient as is consistent with good longitudinal and transverse focussing, and the requirement to maintain a low peak surface electric field. Principle parameters of the resulting design are:

Modulation factor	2.53
Minimum Aperture (radius)	2.85 mm
Synchronous Phase	-30°
Number of cells	21
Overall Length	46.6 cm
Peak surface electric field	120 MV/m
Mean Accelerating Gradient	8.64 MV/m
Inter-Vane Voltage	465 KV

It should be noted that the above electric field gradients represent the upper limit of possible performance for the structure which could still be tested with beam at ATLAS. Achievement of even one-half the above gradients would provide exceptional performance for a cw RFQ.

III. WARM MODEL MEASUREMENTS

A. Electrodynamic Properties

Electromagnetic properties were modeled first numerically, using the MAFIA code, then by measurement with a room-temperature model of the structure with un-modulated vanes set at the average beam aperture (5.03 mm radius).

Table 1
Numerical and Measured Electromagnetic Properties

Parameter	MAFIA	Warm Model
Quadrupole Mode	199.5 MHz	198.6 MHz
Dipole Modes	215.6 MHz	214.9 MHz 214.2 MHz
B_{peak}*	702 Gauss	680 Gauss
E_{peak}*	120 MV/m	
RF Energy*	6.1 Joule	10.1 Joule

* Normalized to an inter-vane voltage of 465 KV

The peak magnetic field is substantially reduced from that reported [3] for an earlier model, primarily because the cross-sectional area of the support posts was more than doubled for the present model. Since superconducting ion-accelerating structures currently in use in the ATLAS linac frequently operate at B_{peak} > 700 gauss [7], in the absence of surface defects, performance limits for the device are expected to be electric-field-induced electron emission rather than magnetic-field-induced losses in the superconductor.

MAFIA results indicate that variation of the rf voltage along any vane is less than 3% [3].

B. Mechanical Properties

Because of the wide quadrupole-dipole mode-splitting, mechanical tolerances are excellent. For the present model, on initial assembly, during which mechanical tolerances of typically .005 inch were maintained, and with no subsequent tuning, the voltages on the four vanes were balanced to better than 10% of mean.

A high-degree of mechanical stability is desirable for low-beam-current applications because of the difficulty of stabilizing the rf phase of high-Q superconducting resonators in the presence of microphonic-induced-excitation of mechanical vibrational modes of the cavities. Measurements of the vibrational properties of the present model have not yet been made. We note however, that measurements on an earlier model showed adequate mechanical stability [3]. Since the support posts for the present model have nearly twice the cross-section and are substantially shorter than for the earlier model, the resonator mechanical stability should be appreciably increased.

III. CONSTRUCTION STATUS AND FUTURE PLANS

The design of the prototype niobium structure is complete. Procurement of niobium and fabrication of tooling are currently underway. RF tests of a prototype unit are expected within the next year.

Primary questions for prototype tests are:
1. Can the high electric surface fields (> 100 MV/m) obtained in a short niobium RFQ be repeated in a structure of useful length?
2. Is the structure sufficiently mechanically stable to permit phase control?
3. Do multipacting phenomena in such a structure present operational problems?

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