CONSTRUCTION OF A SUPERCONDUCTING RFQ STRUCTURE

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Abstract

This paper reports the development 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 length of the structure is 52 cm, and the vanes are modulated to enable tests with an ion beam. The construction of a prototype niobium resonator is described.

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 [2,3,4] for the niobium short-vane RFQ with the following objectives:

1. Explore whether high accelerating fields can be obtained in a superconducting RFQ structure of useful length (50 cm).

2. Provide a structure suitable for testing with beam at the ATLAS heavy-ion facility.

3. Provide sufficient mechanical stability to enable rf phase stabilization with existing systems (for cost-effective operation in low-beam-current applications).

An ATLAS heavy-ion beam can provide considerable flexibility for beam tests[5]. 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 facilitate such testing, the basic parameters for the RFQ design are chosen to be:

Frequency	194 Mhz
Entrance velocity	$\beta_0 = 0.02$
Transverse Emittance	$\epsilon_x = 10\,\pi$ mm-mrad
Longitudinal Emittance	$\epsilon_z = 40\,\pi$ KeV-nsec

Design and Construction

The resonator geometry has been previously described [4]. Although the structure has four-fold rotational symmetry the dipole-quadrupole mode separation is large, yielding ample mechanical

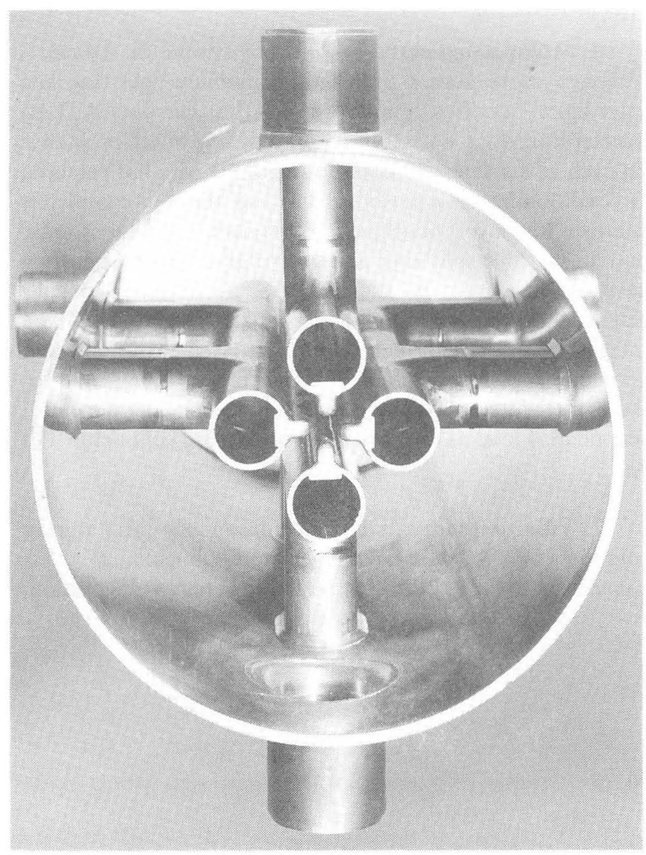

Fig. 1 Major niobium elements of the prototype superconducting RFQ temporarily assembled for tuning prior to final weldment.

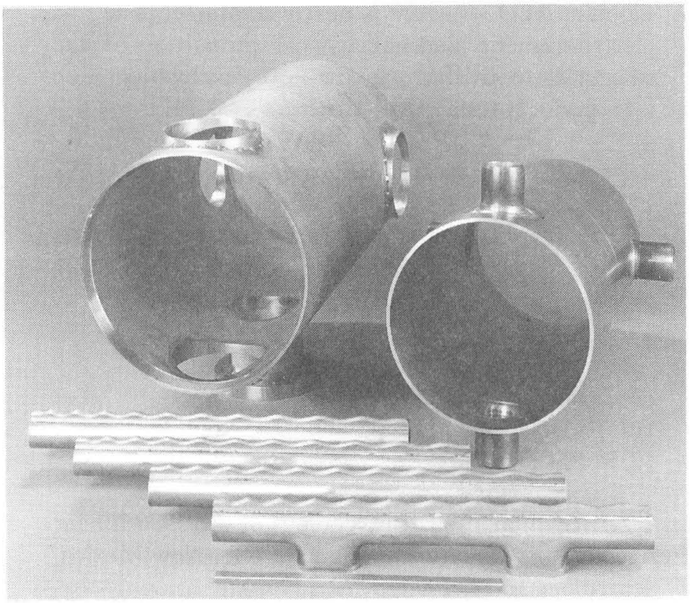

Fig 2 Principal components of the RFQ, including vanes, niobium housing, and stainless-steel outer jacket.

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.

Construction Details

Figure 1 shows the major niobium elements of the prototype superconducting RFQ temporarily assembled for tuning prior to final weldment. The rod and post structures are die-formed in halves from 1/8 inch niobium sheet and then EB welded to form the seams. The resonator outer cylindrical wall is formed of relatively heavy 3/16 inch niobium in order to provide a mechanically stable base for mounting the RFQ vanes.

The niobium cavity is jacketed in a stainless steel housing, shown in Figure 2, forming a liquid helium container through which pass beam ports and rf coupling ports accessing the resonator interior. This design permits operation with a common beam and cryogenic vacuum system (characteristic of superconducting heavy-ion linacs) while avoiding the use of copper-niobium composite material. Where the niobium ports penetrate the stainless-steel housing, welding transitions using a relatively small amount of explosively-bonded niobium stainless-steel composite are employed.

RFQ Vane Design

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.

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:

The vanes are 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.

Some Properties of the RFQ Structure

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

Parameters for the prototype niobium superconducting RFQ structure:

Overall length	47 cm
Minimum Aperture (radius)	2.85 mm
Modulation Factor	2.53

Number of Cells	21
Entrance velocity β_0	0.02
Resonant frequencies:	
Quadrupole mode	198 MHz
Dipole modes	215 MHz
For a vane rf voltage of 100 KV:	
Max. Surface E-field	52 MV/m
Max Surface B-field	292 Gauss
RF energy	1.9 Joule

The superconducting ion-accelerating structures currently in use in the ATLAS linac frequently operate at B_{peak} > 700 gauss [6], 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.

Because of the wide quadrupole-dipole mode-splitting, mechanical tolerances are excellent. For the warm 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 average.

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 micro-phonic-induced-excitation of mechanical vibrational modes of the cavities. Vibration levels observed in the temporary niobium assembly shown in Figure 1 are observed to be less than 50 Hz peak to peak, essentially the same result as measurements on an earlier, copper mode. This level of mechanical stability seems adequate, since the level of vibration is within the reactive power range of existing tuning systems [7,8].

Future Plans

Construction of a prototype superconducting niobium RFQ structure is nearly complete. The electromagnetic and mechanical properties of the structure are satisfactory; the next development step is to perform tests of the structure at 4.2 K.

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