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Niobium Coaxial Quarter-wave Cavities for the New Delhi Booster Linac*

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Abstract

This paper reports the design and construction status of a prototype superconducting niobium accelerating structure consisting of a pair of quarter-wave coaxial-line cavities which are strongly coupled with a superconducting loop. Quarter-wave resonators are two-gap accelerating structures and are relatively short, so that a large number of independently-phased cavities is required for a linac. Strongly coupling several cavities can reduce the number of independently-phased elements, but at the cost of reducing the range of useful velocity acceptance for each element. Coupling two cavities splits the accelerating rf eigenmode into two resonant modes each of which covers a portion of the full velocity acceptance range of the original, single cavity mode. Using both of these resonant modes makes feasible the use of coupled cavity pairs for a linac with little loss in velocity acceptance. Design details for the niobium cavity pair and the results of preliminary tests of multipacting behavior are discussed.

I. INTRODUCTION

The superconducting accelerating structure discussed here is to be employed in a heavy-ion booster linac for the 16UD pelletron electrostatic accelerator at the Nuclear Science Center in New Delhi, India.

Several recent heavy-ion booster linac projects employ superconducting quarter-wave coaxial-line (QWCL) resonant cavities [1 - 7]. The QWCL geometry is characterized by excellent mechanical stability and broad velocity acceptance. Also, QWCL resonators made with superconducting niobium have achieved very high accelerating gradients [5].

A disadvantage of the QWCL geometry, however, is that the single-drift-tube, two gap structure is short, and a relatively large number of independently controlled resonators is required to form a useful linac.

The present project is aimed at developing a high-performance structure based on the QWCL geometry, with the design focussed on reducing construction costs and maximizing operational simplicity and stability.

In what follows, we first discuss the design of a two-gap resonant cavity, usable as a stand-alone structure, then some characteristics of a coupled pair of such cavities. Finally, we discuss the multipacting behavior observed in a superconducting niobium simulation of the drift-tube region of the proposed resonant geometry.

II. RESONANT CAVITY DESIGN

A. General Approach

The design begins with a 100 MHz, two-gap resonant cavity optimized for particle velocity $\beta = v/c = .08$. Such a structure has a large enough range of velocity acceptance that a single resonator geometry will suffice for the entire booster linac, as presently envisioned [7].

Two cavities as described above are being constructed as prototypes, and will be tested, first individually, and then as a coupled pair in order both to test the superconducting coupler and also to ascertain the feasibility of operating the cavities in strongly-coupled pairs, and thus combine the advantages of two-gap and many-gap cavities.

B. Quarter-wave Coaxial-line Cavity

The cavity is formed entirely of niobium, rather than bonded niobium-copper composite as is used in the ATLAS linac and several other accelerators. This choice was taken both because of the cost of forming and welding the composite material, and also because the cost is increased by the relatively large number of two-gap cavities required.

Figure 1 shows a coupled pair of cavities. For the moment, we consider a half of the coupled pair, which constitutes a single QWCL resonant cavity. We note several features:

1. The high-voltage end of the coaxial line consists of a relatively large diameter section which capacitively loads the quarter-wave line and shortens the cavity nearly 20 cm. This is done both to reduce the size of the resonant cavity, and to improve mechanical stability, which decreases rapidly with

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increasing length of the coaxial line. By using a cylindrically symmetric drift tube, large capacitive loading can be obtained while keeping the peak surface electric field low.

2. The niobium cavity is closely jacketed in a vessel of stainless steel, which contains the liquid helium required to cool the superconducting structure. This design permits an array of cavities to operate in a cryostat with the beam-line and cryogenic vacuums being one common system. Such an arrangement is almost universally used in superconducting heavy-ion linacs, because it facilitates the large number of connections to room temperature required to operate an array of independently-phased resonant cavities. A small amount of niobium-stainless bonded composite material is used to provide welding transitions where beam ports and coupling ports penetrate the stainless steel jacket.

3. A pneumatic tuner is incorporated into the bottom end face of the resonant cavity and will consist of a three-section niobium bellows. The end face will move about 3 mm with 1 atm of internal pressure, and provide a tuning range of approximately 100 KHz, substantially more than required for single cavity operation, but necessary for operating the cavities in coupled pairs.

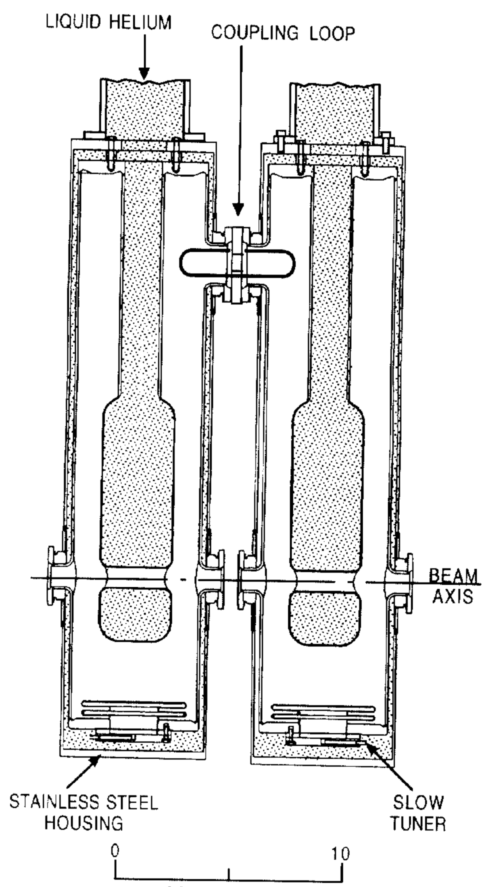

Figure 1. Coupled pair of 100 MHz quarter-wave coaxial-line resonant cavities. The shaded region shows the volume occupied by liquid helium.

C. Electrodynamic Parameters

The QWCL resonant geometry has been modeled numerically and measurements have been performed on a copper model to determine the mechanical properties of the design, which proved entirely satisfactory [7].

Some parameters for a single QWCL resonator (1/2 of a pair) at a nominal accelerating gradient of 1 MV/m are:

Resonant Frequency	95 MHz
Synchronous Velocity	0.081 c
Drift Tube Voltage	86 KV
Energy content	0.116 J
Peak Magnetic Field	108 G
Peak Electric Field	3.9 MV/m
Geometric factor QR_s	18

D. Coupled Cavity Pair

Coupling a pair of QWCL cavities creates a structure in which the two lowest-frequency rf eigenmodes consist of the fundamental rf eigenmode in each of the independent cavities, the two of which can be either in phase (the anti-symmetric mode of the coupled structure) or π radians out of phase (the symmetric mode). As is discussed in reference [7], if each half of the pair can be independently tuned, both modes can be used for beam acceleration, providing a wide range of velocity acceptance.

III. MULTIPACTING TEST

The design chosen could be at risk for severe low-level multipacting for two reasons. The cylindrical drift-tube termination of the QWCL has a high degree of symmetry which might enable multipacting over large areas. Also the drift-tube characteristics, with 3.33 cm gap at 97 MHz, imply an electron transit time that could lead to two-point multipacting at gap voltages in the range 200 - 600 volt, a range in which secondary electron reflection coefficients are generally large. To gain an early indication of multipacting behavior, an existing niobium QWCL resonator was modified by terminating the high-voltage end with a 8.75 inch long, 5.375 inch OD niobium cylinder (coaxial with the 8.0 inch ID of the outer resonator wall). This modification provided a 3.33 cm gap over a substantial area and changed the resonant frequency to 97 MHz.

The modified resonator was electropolished, assembled, cooled to 4.2 K, and the severity of multipacting was observed by logging the time required to RF condition through the multipacting barriers. During the conditioning process, typically 1 watt of RF power was coupled into the multipacting resonator. In figure 2 the conditioning process is shown both after the initial cooldown (Curve 1), and again after warming the resonant cavity to room temperature for several days and cooling again without exposure to air (Curve 2). After conditioning no further multipacting was observed as long as the cavity was maintained below 77 K.

Under similar conditions, the split-ring and interdigital superconducting cavities employed in the ATLAS accelerator typically require one to five hours of rf conditioning to eliminate multipacting. Although multipacting in the present geometry seems appreciably more severe, as manifested by the increased conditioning time, the conditioning process seems entirely effective, and no operational problems are foreseen at this time.

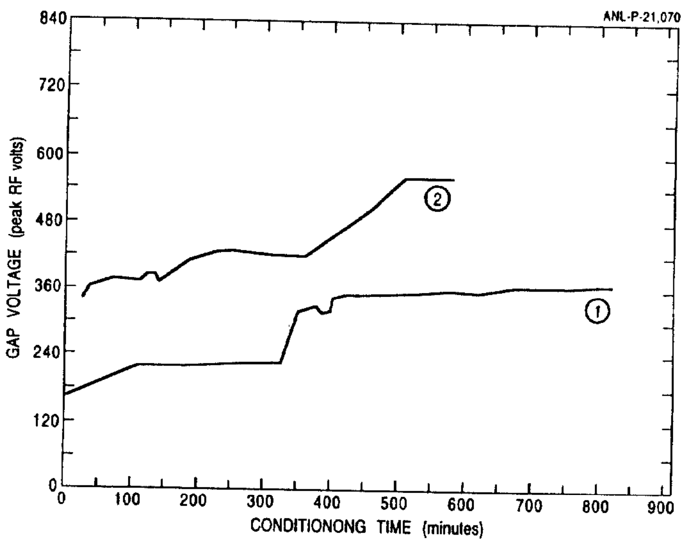

Figure 2 - Multipacting conditioning behavior of a niobium multipacting test cavity at 4.2 K. Multipacting level as a function of conditioning time is shown for (1) the initial cooldown and (2) after warming to room temperature for several days without exposure to air. During conditioning, typically 1 watt was coupled into the cavity.

IV. CURRENT STATUS

Construction of a prototype cavity pair is well advanced. Most of the tooling has been made, and machining and welding of the resonator elements is currently in progress. Completion of the first QWCR and initial cold tests are expected within FY 1993.

V. ACKNOWLEDGEMENTS

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