COUPLED SUPERCONDUCTING RESONANT CAVITIES FOR A HEAVY ION LINAC*

K. W. Shepard and A. Roy+
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60438-4843 USA

Abstract

A design for a superconducting niobium slow-wave accelerating structure has been explored that may have performance and cost advantages over existing technology. The option considered is an array of pairs of quarter-wave coaxial-line resonant cavities, the two elements of each pair strongly coupled through a short superconducting transmission line. In the linac formed by such an array, each paired structure is independently phased. A disadvantage of two-gap slow wave structures is that each cavity relatively short, so that a large number of independently-phased elements is required for a linac. Increasing the number of drift-tubes per cavity reduces 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.

Introduction

This paper reports a design for a superconducting accelerating structure 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 - 6]. 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.

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+Nuclear Science Center, New Delhi, India

Resonant Cavity Design

As a design starting point, we consider a 100 MHz, two-gap structure optimized for particle velocity $\beta = v/c = .08$, which provides a good match for all ions of $A < 100$ from the New Delhi tandem accelerator. A two-gap structure has a large enough range of velocity acceptance that a single resonator geometry will suffice for the entire booster linac, as presently envisioned.

We also consider the possibility of strongly coupling pairs of QWCL cavities to see if a forming a hybrid multi-gap structure could combine some of the advantages of two-gap and many-gap cavities. The object is to reduce the number of resonator rf drive and control systems required, and also the number of transmission lines from room-temperature rf power sources to helium temperature resonant cavities.

In what follows, we first discuss the design of a simple two-gap resonator, intended to be usable as a stand-alone structure, then discuss the characteristics of a coupled pair of such cavities, and finally a design for a superconducting coupling device.

Quarter-wave Coaxial-line Cavity

We choose to form the cavities entirely of pure niobium, rather than employ a bonded niobium-copper composite as in the resonant cavities used in the ATLAS linac and several other accelerators. This decision was taken primarily because of the cost of forming and welding the composite material, and particularly because the cost is increased by the relatively large number of two-gap cavities required.

The cost of high-purity niobium is not negligible, so that an important design consideration is to keep the niobium wall thickness small, yet still achieve good mechanical stability [7].

A coupled pair of QWCR resonators of the geometry chosen is shown in Fig. 1. The electrodynamic and mechanical properties are discussed in detail in following sections, we wish here to consider a single QWCL resonant cavity, one-half of the coupled pair, and note the following 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

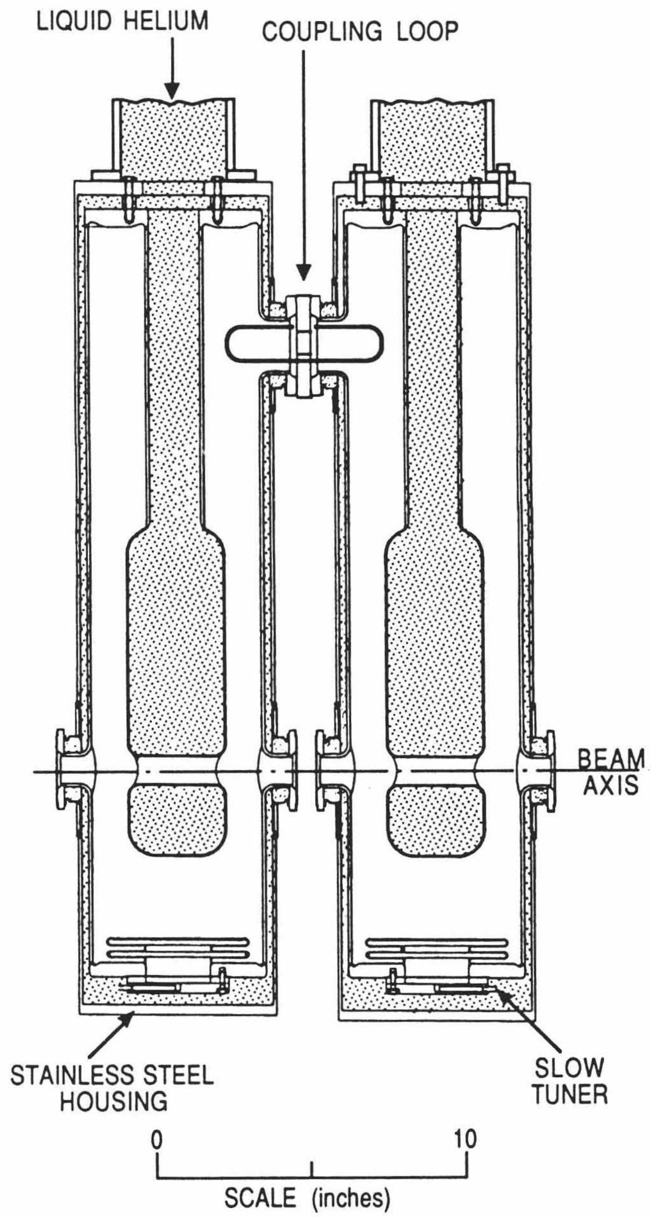

Fig. 1. Coupled pair of 100 MHz quarter-wave coaxial-line resonant cavities. The shaded region shows the volume occupied by liquid helium.

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 will contain the liquid helium required to cool the superconducting structure. This design will permit 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 will be 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 which is essential, as is discussed below, for operating the cavities as coupled pairs.

Coupled Cavities

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 (which we term the anti-symmetric mode of the coupled structure) or π radians out of phase (the symmetric mode).

Figure 2 shows the transit-time-factor (TTF) as a function of particle velocity ß (the velocity acceptance characteristic), both for a single QWCL cavity and also for a coupled pair of such cavities. The TTF is normalized to unity for an energy gain of twice the peak rf voltage summed over the drift-tubes traversed by the charged particle.

If we compare the TTF curve for a single resonator with the symmetric mode of the coupled pair, we are simply comparing a two-gap and a four-gap accelerating structure, and with the obvious conclusion that the velocity acceptance of a two-gap structure is substantially broader than for a four-gap structure.

If, however, we permit the coupled pair to operate in either the symmetric or anti-symmetric mode, we can obtain a velocity acceptance curve which is the envelope of the curves for both pair modes shown in Fig. 2, and obtain a velocity acceptance which is essentially as broad as for each

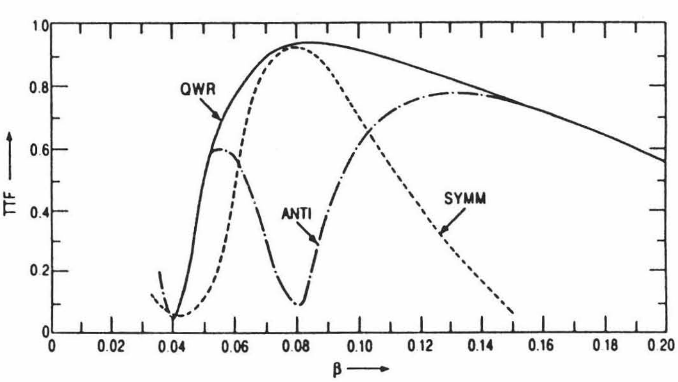

Fig. 2. Energy gain as a function of particle velocity ß = v/c for single and paired QWCL resonators. Details of the various curves are discussed in the text.

of the short, two-gap structures constituting the pair.

The symmetric and anti-symmetric modes are, however, at two different frequencies, so that employing both modes in a linac requires that the coupled pair be tunable over a sufficient range that either mode can be made coincident with the linac rf clock.

The two modes are split by an amount proportional to the coupling between the resonators, which has a minimum value determined by the requirement that the coupled cavities operate stably as a single unit. In the present design, we require that the relative amplitude of the rf fields in the two cavities remain constant to better than 1 part in 10^3 in the presence of fluctuations in the eigenfrequencies of the two resonators caused by microphonic acoustic excitation. At this level, fluctuations in the rf field will cause no appreciable increase in longitudinal emittance of the beam for the application considered.

The coupler shown in Figure 1 consists of a loop, connected to a flange that demountably joins the coupling port on each paired cavity. The loop extends into the (primarily magnetic) rf field of each cavity as shown. Coupler parameters are discussed in the next section.

Room Temperature Model

The QWCL resonant geometry has been modeled in copper (using a 3 mm wall thickness) to allow measurement of the mechanical properties of the design. Fundamental 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	253 KV
Energy content	0.116 J
Peak Magnetic Field	108 G
Peak Electric Field	3.9 MV/m
Geometric factor QR_s	18

Mechanical properties of the model were also observed. Microphonic induced rf eigenfrequency fluctuations were less than 10 Hz peak-peak under ambient conditions typical for the existing ATLAS linac. The observed level of sensitivity to microphonics is about a factor of five less than for the existing ATLAS split-ring resonators and shows the mechanical stability of the design to be excellent.

The coupler shown in Fig. 1 provides sufficient coupling to split the symmetric and antisymmetric modes by 50 KHz. This coupling is more than a factor of five stronger than needed to stabilize for the microphonic effects observed. Measured rf magnetic fields at the coupling ports indicate that rf losses in a demountable joint to the coupler will be acceptable at accelerating gradients of more than 6 MV/m [8]. It should be noted that the coupler must be superconducting: the rf current in the coupling loop will be 65 amperes at an accelerating gradient of 1 MV/m, making losses in a copper structure unacceptable.

Discussion and Conclusions

An additional feature of the coupled pair structure, when as in the present design both elements can be independently tuned, is that the field level in the two halves can be independently varied over a substantial range. This possibility may be of value in permitting each element can undergo independent high-filed conditioning, and also each element can be independently operated at its maximum achievable field level.

A major issue which can be resolved only by testing a superconducting prototype is the nature and severity of multipacting in the cylindrically symmetric cavity. Also, determining the practicality of using both modes of a coupled pair will require a series of tests of the paired structures.

Construction of a prototype cavity pair is currently in progress with the first cold tests expected within the next year.

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References

1. I. Ben-Zvi and J.M.Brennan, Nucl.Instr.and Meth.212, p73-79, (1983).
2. K. W. Shepard et al., IEEE Trans. Magn. MAG-21, p146, (1985).
3. D.W.Storm et al., Proc. of the 2nd Workshop on RF Superconductivity, Geneva, p. 173, (1984).
4. D. W. Storm et al., Nucl.Instr. and Meth. A287, p. 247 (1990).
5. S.Takeuchi, Proc. of the 5th Workshop on RF Superconductivity, DESY, p. 76 (1991).
6. A.Facco et al., Proc. of the 5th Workshop on RF Superconductivity, DESY, p. 58 (1991),
7. J. M. Bogaty, et al., Proc. of the 1989 IEEE Particle Accelerator Conference, May 20-23, 1989, Chicago, Illinois, p1978 (1989).
8. in ATLAS - a Proposal for a Heavy-ion Accelerator, Physics Division, Argonne National Laboratory (1978).