NIOBIUM COAXIAL QUARTER-WAVE CAVITIES*

K. W. Shepard
Argonne National Laboratory
9700 South Cass Avenue, Argonne, IL 60439 USA

A. Roy and P. N. Potukuchi
Nuclear Science Centre
JNU New Campus, P.O. Box 10502, New Delhi-110067 INDIA

Abstract

This paper reports the development status of a superconducting niobium coaxial quarter-wave line accelerating structure to be used in a heavy-ion booster linac following the 16UD pelletron electrostatic accelerator at the Nuclear Science Center, New Delhi. The 97 MHz, single drift-tube niobium structure is housed in an integral stainless-steel jacket, to permit a common beam-line and cryogenic vacuum in the linac, but using only niobium (rather than niobium-copper composite material) in the outer rf cavity wall. The cavity is tunable over a range of several hundred KHz by deforming a section of the cavity wall by as much as 2 mm. The tuning section is a niobium "bellows" assembly pneumatically extended with helium gas up to one atmosphere in pressure. The coaxial-line cavity is designed to permit strongly-coupling cavities in pairs, thus reducing the number of independently-phased elements required for a heavy-ion linac. Results of initial cold tests are discussed.

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.

*This work is being performed at Argonne, and is funded through the Nuclear Science Center, New Delhi by the University Grants Commission of the Government of India

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, the results of initial cold tests of a prototype niobium cavity are discussed.

Resonant Cavity Design and Fabrication

Figure 1 shows a coupled pair of coaxial-line cavities. Each 100 MHz, two-gap resonant cavity (half-pair) is optimized for particle velocity $\beta = v/c = .08$. Such a structure has a broad enough of velocity acceptance that a single resonator geometry will suffice for the entire booster linac, as presently envisioned [7].

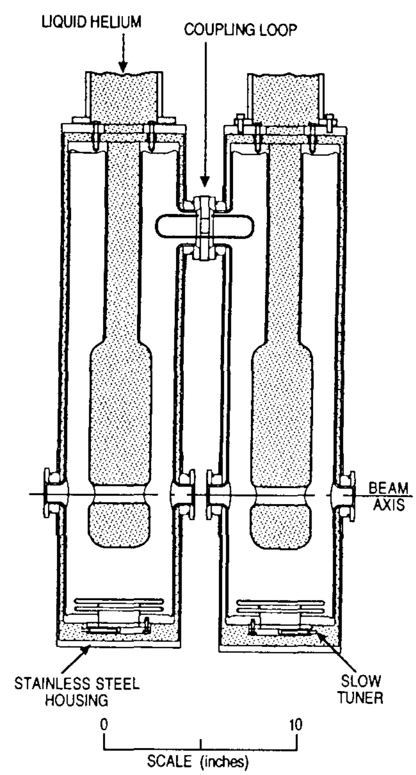

Figure 1. Coupled pair of 100 MHz quarter-wave coaxial-line resonant cavities. The shaded region shows the volume occupied by liquid helium.

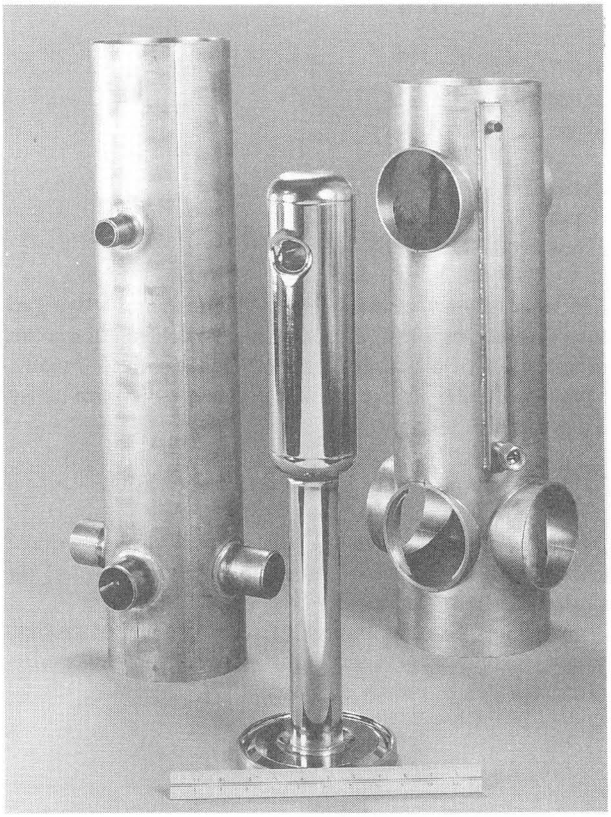

Figure 2 - Major components of the niobium quarter-wave coaxial-line cavity prior to final weldment. Elements shown are the quarter-wave line and drift-tube, the 6.5 inch OD niobium outer housing and the 7.5 inch OD stainless-steel outer jacket.

Several cavities as described above are being constructed as prototypes, and are being tested first individually, but eventually as a coupled pair to ascertain the feasibility of operating the cavities in strongly-coupled pairs, and thus combine the advantages of two-gap and many-gap cavities.

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 this cost is further increased by the relatively large number of two-gap cavities required.

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. By using a cylindrically symmetric drift tube, large capacitive loading can be obtained while keeping the peak surface electric field low. This is done both to reduce the size of the resonant cavity, and to improve mechanical stability, which decreases rapidly with increasing length of the coaxial line. The outer cavity wall is fabricated from as thin (1/8 inch) a niobium sheet as still provides adequate mechanical stability.

2. The niobium cavity is closely jacketed in an outer vacuum 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 vacuum and cryogenic vacuum 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 short, independently-phased resonant cavities. Where the outer jacket and niobium resonator join, i.e. at all beam ports and coupling ports, a flange made of explosively-bonded niobium and stainless steel is used to provide a welding transition between the two materials.

3. A pneumatic tuner is incorporated into the bottom end face of the resonant cavity and consists of a two-section niobium bellows. The end face moves about 2 mm with 1 atm of internal pressure, and provide a tuning range of approximately 70 KHz, substantially more than required for single cavity operation, but required for operating the cavities in coupled pairs.

Prototype Cavity Parameters

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

Resonant Frequency	97.0 MHz
Synchronous Velocity	0.08 c
Drift Tube Voltage	85 KV
Energy content	0.099 J
Peak Magnetic Field	100 G
Peak Electric Field	3.6 MV/m
Geometric factor QR_s	17.3
Active Length	15.9 cm

Of two prototype cavities one is complete and the second is nearly complete. No particular problems were encountered in fabrication, standard sheet metal forming techniques and electron-beam welding procedures were used throughout. The cavities are tuned to final frequency by temporarily assembling, testing, and adjusting the cavity length prior to the final weldments. Niobium components less than 18 inches maximum dimension are heat-treated at 1250 C in the available vacuum furnace, which is too small to permit heating of the entire cavity after final weldments.

Results and Conclusions

Several cold tests have been performed on the first completed prototype cavity. The following characteristics have been observed at 4.2 K:

Resonant Frequency	96.78 MHz
Radiation-Pressure-Induced RF Frequency Shift	≈ 4 Hz/(MV/m)^2
Helium System Pressure Induced RF Frequency Shift	250 Hz/psi
Q_0	1.7×10^7
Accelerating Field	2.2 MV/m (cw) 5.2 MV/m (pulsed)

The resonator Q and field level are at present limited by either a defective e-beam weld or defective niobium material in the niobium flange at the shorted end of the coaxial line. Diagnostic and repair work is currently underway on this cavity.

Although some development tasks remain, several important properties of the present design are established:

1. Multipacting in the cylindrically symmetric structure, although more severe than in the niobium split-ring and interdigital cavities employed in the current ATLAS accelerator, does not seem to present any novel problems. In each of six separate cool-downs, the cavity has required rf conditioning for a period of 14 to 18 hours to completely remove low-level multipacting barriers. 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 multipacting does not reappear as long as the cavity temperature is kept below 100 K.

2. Vibration-induced RF eigenfrequency jitter during cold tests in a realistic linac environment, including connection to the ATLAS recirculating helium refrigeration system, was typically 10-20 Hz peak to peak. The mechanical stability of the structure as fabricated of 1/8 and 1/16 inch niobium sheet is excellent.

3. The stainless-steel outer jacket (joined to the niobium resonator at the coupling ports using explosively-bonded niobium to stainless-steel welding transitions) has proven reliable in exhibiting no observable vacuum leaks although repeatedly cycled over the range 4 K to 373 K.

4. The resonator is cooled and warmed by circulating gas through two small channels welded to the outer stainless steel jacket. The thermal relaxation time of the resonant cavity, via convection in 1 atm pressure helium, to these channels is roughly 4 hours, providing for rapid cooldown and warmup of the system.

Acknowledgements

The authors would like to thank Mark Kedzie of Argonne Physics Division for assistance in processing and testing the prototype cavity.

References

1. I. Ben-Zvi and J.M.Brennan, Nucl.Instr.and Meth.212, p73-79, (1983).

2. K. W. Shepard, S. Takeuchi, and G. P. Zinkann, IEEE Trans. Magn. MAG-21, p. 146 (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. K. W. Shepard and A. Roy, Proc. of the 1992 Linear Accelerator Conference, August 24-28, 1992, Ottawa, Canada, p. 441, (1992).