DEVELOPMENT OF SUPERCONDUCTING NIOBIUM
ACCELERATING STRUCTURES FOR HEAVY IONS*K.W. Shepard, S. Takeuchi⁺, and G.P. Zinkann
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PORTIONS OF THIS REPORT ARE ILLEGIBLEIt has been reproduced from the best
available copy to permit the broadest
possible availability.Summary

Results of tests of two new designs for superconducting niobium resonant cavities are presented. Both types resonate at 145.5 MHz and accelerate most efficiently for particle velocities $\beta = v/c = 0.16$. One resonator is of the split-ring type, but of a simpler design than a previously reported $\beta = .16$ unit. Although the surface fields are higher, the performance is somewhat better than for the earlier design: an accelerating field $E_a = 4.3$ MV/m has been obtained at 4.2K with 4w of rf input, where E_a is defined as the energy gain per unit charge for a synchronous particle averaged over the interior resonator length. The other resonator is an 8-inch OD tapered coaxial quarter-wave line terminated with a drift tube of 1.50 inch aperture. At 4.2K, this resonator exhibits a low-level Q of 2×10^9 , and has achieved $E_a = 4.7$ MV/m with 2.8w of rf input.

Introduction

The Argonne superconducting heavy-ion linear accelerator (ATLAS) consists of an array of forty-six niobium split-ring resonant cavities of three different basic types.^{2,3,4} Each type can

Figure 1 - Three split-ring resonators used for the ATLAS accelerating system. From left to right are the H-type (97 MHz, $\beta = .1$); S-type (145.5 MHz, $\beta = .16$); and L-type (97 MHz, $\beta = .06$).

*Work performed under the auspices of the U.S. Department of Energy.

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Figure 2 - Resonator Q vs. accelerating field level E_a , measured at 4.2K. Curve V is for the V-type split-ring resonator with an interior length of 35.6 cm. Curve Q is for a coaxial quarter-wave line resonator with a 20.3 cm interior length.

effectively accelerate over a range of a factor of two in particle velocity. The first two types developed were optimized for particle velocities $\beta = .06$ (L-type), and $\beta = .1$ (H-type).

This paper reports a third class of split-ring resonator optimized for particle velocities $\beta = 0.16$, developed for the ATLAS extension to the linear accelerator.^{1,5}

Also reported is development of a niobium coaxial quarter-wave line resonator.⁶ This class of resonator exhibits very good mechanical stability which may allow the development of superconducting resonant cavities for the acceleration of particles with velocities less than $0.01c$.⁷

In what follows, we first give a brief description of the split ring resonators previously

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TABLE I. - Properties of Several Argonne Superconducting Resonator Geometries

Type	Optimum Velocity	Frequency	Peak Surface Electric	Fields Magnetic*	rf Energy*	Static Frequency Shift*	Length
L	0.065 c	97.0 MHz	4.85 MV/m	142 G	0.073 J	59 Hz	20.3 cm
H	0.105	97.0	4.80	185	0.147	112	35.6
S	0.155	145.5	3.9	140	0.159	67	35.6
V	0.155	145.5	4.80	260	0.120	59	35.6
Q	0.145	140.0	5.1	141	0.090	5	20.3

* referenced to an accelerating field level $E_a = 1$ MV/m.

developed. Then the development of $\beta = .16$ split-ring resonators for the ATLAS extension to the linac is discussed. Finally, the recent development of a niobium coaxial quarter-wave line resonator is presented.

Split-Ring Resonators

Figure 1 shows the three types of split-ring resonators so far developed at Argonne and produced in quantity for the heavy-ion linac. In Figure 1, the demountable end-plates of the resonators are removed to show the all-niobium split-ring loading structure. The outer housing has a 16-inch ID and is formed of an explosively-bonded niobium-copper composite. Table I shows the principal electrodynamic parameters of these resonators.

For the ATLAS accelerator, two versions of a split-ring resonator optimized for particle velocities $\beta = 0.16$ and useful for velocities from .1 to .25c have been developed. This has been accomplished primarily by increasing the frequency of operation of the existing H-type resonator. At the same time, in the initial version of this resonator (S-type), the drift-tubes were redesigned to substantially decrease the surface electric field. This was done in hope of obtaining higher accelerating gradients. In order to accommodate the larger drift-tubes, an elliptically-sectioned loading arm was required.^{1,5}

However, after building and testing three such resonators, we found that electron-loading was not reduced with respect to the H-type, but in fact was slightly worsened.

Thus a simpler version (V-type) of this resonator was made by simply shortening the inductive loading arms of the H-type design until the desired frequency was obtained. The surface electric field was unchanged by this procedure, and the surface magnetic field increased by about 40%. However, the expected peak value of surface magnetic field in this resonator is less than the critical field of superconducting niobium, so that the increase in this parameter should have no substantial effect on performance.

Typical performance for the V-type resonators is shown in Figure 2, curve V, and is significantly

better than for the S-type, even though the surface electric field is substantially higher. Also, the construction costs are lower, so that the V-type are being used to complete the ATLAS linac.

Coaxial-Line Resonators

Figure 3 shows the several components of a coaxial quarter-wave line resonator before final welding. Design and construction of this resonator was stimulated by the work of Ben-Zvi and Brennan at SUNY at Stony Brook with a coaxial-line resonator.⁶ The resonator shown extends the Stony Brook results in two respects: firstly, the superconducting material used is niobium, rather than lead electroplated onto copper, yielding a resonator

Figure 3 - Components of a coaxial quarter-wave line resonator before final assembly. The scale shown is in inches.

of substantially higher performance; secondly, the optimum particle velocity has been increased from $\beta = v/c = 0.08$ to $\beta = 0.14$. This is a non-trivial extension, as a proportionally larger resonator is required, which must support larger rf voltages.

The resonator has an outer conductor made of niobium bonded to copper and formed into an 8 inch ID cylinder. The center conductor is 12 inches long and tapers from a diameter of 2.5 inches at the base to 1.25 inches where it joins a 4-inch OD drift tube with a 1.50 inch beam aperture. The resonant frequency is 140 MHz.

Figure 2 curve Q shows the performance obtained at 4.2K. The maximum field level obtained was E_a 4.7 MV/m with 2.8 watts of rf input. A thermal-magnetic instability caused by a defect on the outer housing limits cw operation at this level.

The mechanical stability of the resonator is excellent, the static rf eigenfrequency shift being 5 Hz at $E_a = 1$ MV/m.

Discussion and Conclusions

With the successful development of the V-type split-ring resonator, superconducting niobium accelerating structures have been developed which provide excellent performance, and cover a range of particle velocities from .04c to .23c.

A surprising result, for which we have at the moment no explanation, is that between the V and S-type resonators, performance does not scale with surface electric field. The S-type resonator exhibits more electron-loading than the V-type, even though the surface electric field is 19% lower for the S-type.

Performance obtained to date with the Q-type coaxial quarter-wave line resonator shows that construction of this geometry with superconducting niobium is straightforward and provides outstanding performance. The exceptional mechanical stability of this geometry opens the possibility of going to

low resonant frequencies by increasing the length of the quarter-wave line.

Going to low frequencies, e.g., 48.5 MHz, and terminating a coaxial line with two drift-tubes to form a four-gap accelerating structure would provide a resonator matched to particle velocities of 0.008c. Initial design work indicates that a superconducting resonator with the above characteristics can be made with acceptably low surface fields and adequate mechanical stability.⁷ Successful development of this type of resonator would make possible a linear accelerator which could be directly injected by an ECR positive-ion source. Such a linac could replace the present electrostatic injector of ATLAS and increase both the beam current and mass range of the facility.

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