A SUPERCONDUCTING ACCELERATING STRUCTURE FOR PARTICLE VELOCITIES FROM 0.12- TO 0.23-C*

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Abstract

A split-ring resonator has been designed for an optimum particle velocity $\beta = v/c = 0.16$ and a frequency of 145.5 MHz. The ratio of peak surface electric field to effective accelerating field in the resonator has been reduced 20% from the value obtained in previously developed split-ring resonators. The improved design results from the use of elliptically-sectioned loading arms and drift-tubes which have been enlarged to reduce peak surface fields and also shaped to eliminate beam steering effects in the resonator. All fabrication problems presented by the more complex geometry have been solved and a prototype superconducting niobium resonator has been completed. An accelerating field of 3.3 MV/m at 4 watts rf input has been so far achieved, corresponding to an effective accelerating potential of 1.17 MV per resonator.

Introduction

This paper describes the current status of development of a superconducting niobium split-ring resonator designed for particle velocities $\beta = v/c = 0.16$. The resonator extends the velocity range of previously developed split-ring structures by 54%, and is intended for use in the ATLAS addition to the existing Argonne superconducting heavy-ion linac.

The linac is presently an array of two types of split-ring resonators, which accelerate most efficiently for a particle velocity $\beta_o = .06$ for the low-beta, and $\beta_o = 0.1$ for the high-beta structure.[1,2] Each type accelerates with more than 80% of optimum efficiency for a range of velocities $.76\ \beta_o \leq \beta \leq 1.42\ \beta_o$.

Because of the limited velocity range, to extend the heavy-ion linac by adding resonators of the $\beta_o = .1$ type would give less than optimum performance for the lighter ions. Thus development of a higher velocity split-ring structure was undertaken.

In what follows, the design and construction of a prototype niobium resonator is described, the results of tests of the prototype are presented, and the remaining development tasks discussed.

Design and Construction

The resonator, shown in Fig. 1, seems best described in terms of changes from the $\beta_o = .1$ split-ring. The drift-tube diameter has been increased from 10 to 12 cm, allowing an increase in the radius of curvature at the ends of the drift tubes, which decreases the peak surface electric field as shown in Table I. The resonant frequency of the accelerating mode has been increased from 97 to 145.5 MHz, primarily by decreasing the length of the loading arm from 50 to 30 cm. The increase in frequency causes a proportionate increase in the rf current in the loading arm for a given accelerating field. To keep the peak surface magnetic field within acceptable limits, the loading arm diameter is increased from 3.2 cm to 5.1 cm.

The increased size of the drift tubes and loading arm within the fixed 16 inch resonator diameter reduces the radial clearance between the various elements and caused objectionably large surface electric fields along the loading arms. This problem is overcome by making the cross-section of the loading arm elliptical with the major axis parallel to the beam-axis. An additional advantage of the elliptical geometry is a 15% reduction in peak surface magnetic field. The ellipse chosen has a major diameter of 5.84 cm and a minor diameter of 4.26 cm.

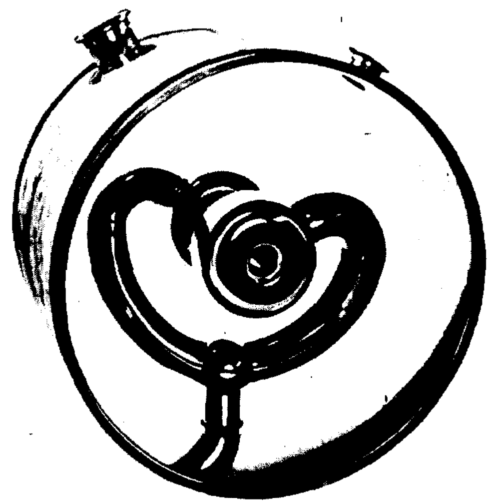

Fig. 1. 145.5 MHz, $\beta_o = .16$ niobium split-ring resonator. The interior diameter is 16 inches. The end-plates are removed to show the resonator interior.

As is shown in Table I, the electrodynamic properties of the resonator are satisfactory in all respects.

Table I. Comparison of the principal electrodynamic properties of the $\beta_o = .16$ and the lower velocity split-ring resonators.

Optimum Velocity	Resonant Frequency	Peak Surface Fields* Electric	Magnetic	RF Energy Content*
.066	97 MHz	4.8 MV/m	129 G	.069 J
.106	97	4.7	182	.147
.163	145.5	3.9	145	.159

*At an effective accelerating field $E_a = 1$ MV/m.

The general method of construction is the same as for the previously developed niobium split-ring resonators. I.e., the cylindrical housing is made from an explosively bonded niobium-copper composite, while the split-ring loading structure is made of Stanford-

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grade niobium, formed by standard sheet-metal techniques and joined by electron-beam welding.

The major point of difference from the previously developed resonators, and the major source of difficulty in construction, is the elliptically-sectioned loading arm. In earlier resonators, the loading arms, of circular cross section, were formed by bending a drawn niobium tube. The present elliptically sectioned loading arms are each made of four die-formed sections, joined by five electron beam welds.

The loading arms are the only part of the resonator required to carry a substantial rf current, and the rf superconducting properties of this element are critical. The present design calls for fourteen electron beam welds in this region, as compared with four welds in the earlier structures. Thus a new construction problem is the considerably increased reliability required of the welding process.

Prototype Tests

In test at 4.2 K, the prototype resonator has exhibited multipacting (mp) behavior different from the earlier split-ring resonator in that an mp barrier at $E_a \approx 0.1$ MV/m does not condition away with the continued application of rf power.[3] This multipacting level is strongly coupled to a 134 MHz rf mode in which the drift-tube voltages are symmetric rather than antisymmetric, as in the 145.5 MHz accelerating mode. It was found that rf conditioning of the 134 MHz mode to high field levels was possible and that after such conditioning the mp barrier at 0.1 MV/m in the 145 MHz mode was no longer present. It should be noted that, in the lower velocity split-ring resonators, the symmetric rf mode is higher in frequency than the accelerating mode and no intractable mp barriers are found.

After conditioning, at 4.2 K, the maximum attainable field was limited by a thermal instability to $E_a < 1.9$ MV/m. Second-sound time-of-flight thermometry located the source of thermal instability at a structural weld joining the two major sections of a loading arm. Microscopic examination of the suspect weld showed no visable defect, such as fissures or cracks, at the surface of the weld.

The split-ring loading structure was removed from the resonator housing and a "cosmetic" reweld of the suspect joint was performed which re-melted the outer .020 inch of the .062 inch wall of the loading arm. Subsequent testing (Fig. 2, curve 1) showed the resonator Q to be increased, but the thermal instability at $E_a = 1.9$ MV/m remained. Second-sound diagnostics showed the location of the field-limiting defect to be unchanged.

Following this test, extensive x-ray examination showed structural flaws, such as lack of penetration, in several welds including the suspect weld. Rather than continue attempts to patch the apparently defective weld, it was decided to construct a second split-ring assembly.

For the second prototype, the thickness of niobium in the elliptical loading arms was increased from .063" to .094". All EB welds were extensively x-rayed, and were not accepted if there was any evidence of porosity or lack of penetration.

The second split-ring was welded into the same cylindrical housing used for the first prototype, and has been tested several times. Typical performance is shown in Fig. 2, curve 2. The decrease in Q for $E_a >$ 2 mV/m is accompanied by x-ray emission characteristic of electron-loading. The accelerating gradient with 4 watts of rf input power is presently 3.3 MV/m, corresponding to an effective accelerating potential of 1.17 MV for the resonator.

Phase stabilization of the resonator should be straightforward, since mechanical stability is good. At an accelerating field $E_a = 1$ MV/m the radiation-pressure induced eigenfrequency shift was $\Delta f/f \approx 9 \times 10^{-7}$ for the first prototype. The second prototype, with increased wall thickness in the loading arms, is somewhat stiffer and $\Delta f/f = 6 \times 10^{-7}$

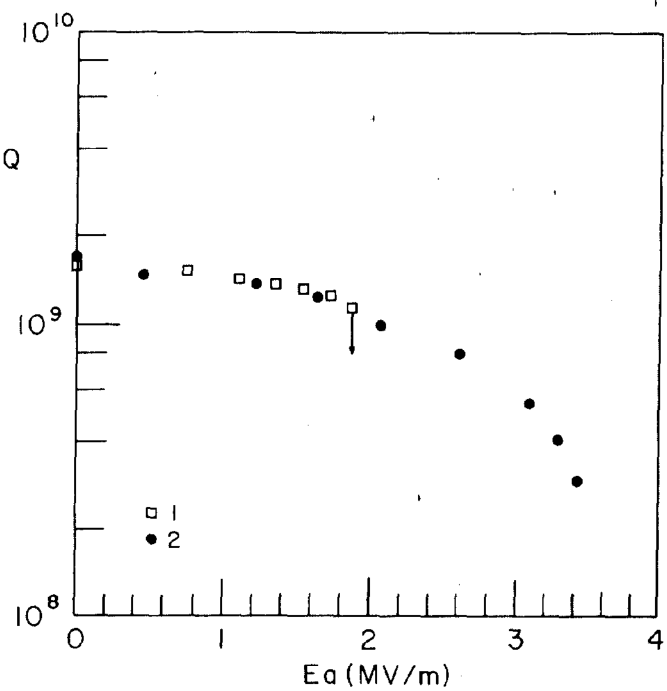

Fig. 2. Resonator Q vs Accelerating Field Level at 42 K.

Curve 1 is for the first prototype which was thermally unstable at $E_a = 1.9$ MV/m because of a defective weld.

Curve 2 is for the second prototype which is limited by electron loading.

Discussion and Conclusions

Although the field levels achieved can provide a useful accelerating gradient they are 20% lower than for the previously developed Nb split-ring structures. Thus development is continuing, focussed on reducing electron loading.

Two approaches are being explored. The first is to condition the cold resonator with brief pulses of high rf power, for which an rf source is being constructed. The second is an attempt to identify uncontrolled variables in surface preparation techniques, which is motivated by the fact that several of the 30 resonators of the earlier designs so far constructed have exhibited electron loading at field levels comparable to those obtained with the present resonator.

References

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