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 β = v/c = 0.16 and a fre-
quency of 145.5 MHz. The ratio of peak-surface electric
field to effective accelerating field in the re-
sonator 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
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to eliminate beam-steering effects in the resonator.

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All fabrication problems presented by the more-complex
gometry have been solved, and a prototype supercon-
ducting 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 devel-
lopment of a superconducting niobium split-ring re-
sonator designed for particle velocities β = v/c = 0.16.
The resonator extends the velocity range of previously
developed split-ring structures by 54%, and is intend-
ed 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 effi-
ciently for a particle velocity βo = .06 for the low-
beta, and βo = 0.1 for the high-beta structure. Each type accelerates with more than 80% of optimum
efficiency for a range of velocities β o ≤ β ≤ 1.42
βo.

Because of the limited velocity range, to extend
the heavy-ion linac by adding resonators of the βo = .1 type would give less than optimum performance for the
lighter ions. Thus development of a higher velo-
city splitting 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 re-
aining development tasks discussed.

Design and Construction

The resonator, shown in Fig. 1, seems best de-
scribed in terms of changes from the βo = .1 split-
ing. 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 tube, which de-
creases 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, primar-
ily 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.

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

<table>
<thead>
<tr>
<th>Optimum Velocity</th>
<th>Resonant Frequency</th>
<th>Peak Surface Fields</th>
<th>RF Energy Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>.066</td>
<td>97 MHz</td>
<td>4.8 MV/m</td>
<td>129 G</td>
</tr>
<tr>
<td>.106</td>
<td>97</td>
<td>4.7</td>
<td>182</td>
</tr>
<tr>
<td>.163</td>
<td>145.5</td>
<td>3.9</td>
<td>145</td>
</tr>
</tbody>
</table>

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

*Work performed under the auspices of the Office of

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

Fig. 1. 145.5 MHz, βo = .16 niobium split-ring re-
sonator. The interior diameter is 16 inches. The end-
plates are removed to show the resonator interior.
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. 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. Macroscopic examination of the suspect weld showed no visible 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" reveld 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 $\Delta f/f = 9 \times 10^{-7}$ 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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