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SPLIT RING RESONATOR FOR THE ARGONNE SUPERCONDUCTING HEAVY ION BOOSTER*

K. W. Shepard, C. H. Scheibelhut, R. Benaroya, and L. M. Bollinger

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

A split-ring resonator for use in the ANL superconducting heavy-ion linac has been constructed and is being tested. The electromagnetic characteristics of the 98-MHz device are the same as the unit described earlier, but the housing is formed of a new material consisting of niobium sheet explosively bonded to copper. The niobium provides the superconducting path and the copper conducts heat to a small area cooled by liquid helium. This arrangement greatly simplified the cryogenic system. Fabrication of the housing was relatively simple, with the result that costs have been reduced substantially. The mechanical stability of the resonator and the performance of the demountable superconducting joints are significantly better than for the earlier unit.

Introduction

This paper describes work in progress toward development of a superconducting niobium split-ring resonator[1] for use in the Argonne heavy-ion energy booster[2]. The 98 MHz resonator, shown in Figure 1, has the same electromagnetic properties as the resonator previously described[3]. However, several major design changes have been made.

The principle change is that the cylindrical housing and ends of the resonator have been formed from a composite material consisting of niobium explosively bonded to copper[†]. This allows the niobium to be cooled by thermal conduction through the copper, eliminating the need for circulating liquid helium around the resonator housing. This approach was chosen to reduce resonator construction costs, simplify the cryogenic system, and to increase the mechanical rigidity of the resonator. Both ends of the resonator are removable to facilitate electropolishing. The demountable, rf current-carrying joints required have been modified to improve rf loss characteristics.

In what follows, properties of the niobium-copper composite material are briefly discussed, then the construction, testing, and development to date of the resonator are described.

Resonator Design and Construction

Explosively Bonded Niobium-Copper Material

The niobium-copper composite was formed with 1/16 inch niobium sheet[††], explosively bonded to cold-rolled, ETP copper plate. The bond provides good thermal contact to the niobium and withstands repeated cycling to liquid helium temperatures. No superfluid helium leaks along the niobium-copper bond have been observed.

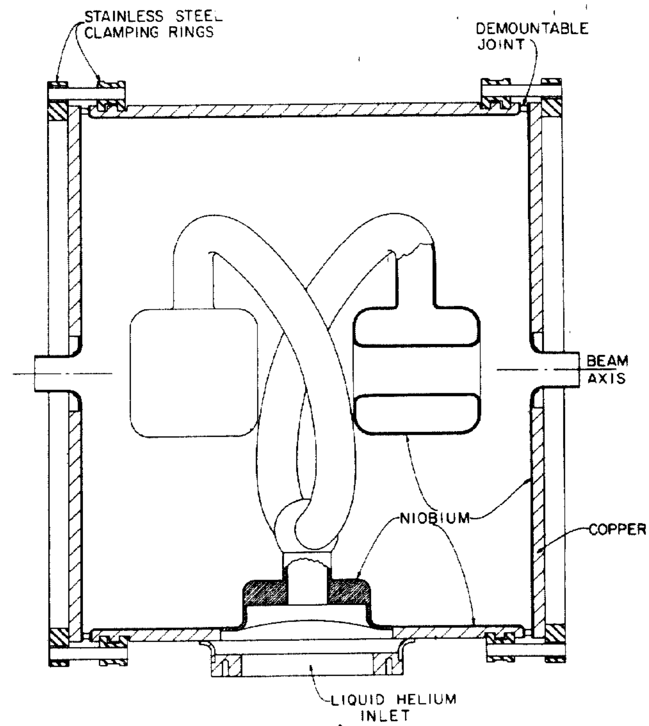

Figure 1. Section of the niobium split-ring resonator. The outer housing is made with an explosively bonded niobium-copper composite.

An upper bound on the surface resistance R_s of samples of the material was obtained by removing all but 1/16 inch of the copper and forming a tube 1 inch in diameter and 15 inches long. The tube was used as the center conductor of a superconducting, $\lambda/4$ resonant coaxial line[3]. Measured at 4.2K and 193 MHz, the observed resonator Q implied $R_s < 1.5 \times 10^{-7}\ \Omega$ for the composite material for rf surface magnetic fields up to 200 gauss.

The composite material can be formed by ordinary sheet metal techniques such as rolling and die-forming. Joining has been accomplished by electron beam welding the niobium after removing all copper to a distance of 1/8 inch from the weld line.

The Resonator

The cylindrical housing was made from 3/8 inch copper plate clad on one side with 1/16 inch niobium, rolled to a 16 inch ID and seam welded opposite the split ring mounting flange, where the surface magnetic field is a

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†Performed by Northwest Technical Industries of Port Angeles, Washington

††Stanford Grade, supplied by the Teledyne Wah Chang Corp.

minimum. At the ends of the cylinder, some of the copper was removed and the niobium rolled outward to provide a flange surface for a superconducting demountable joint.

The end plates were made of 1/4 inch copper clad on both sides with 1/16 inch niobium in order to eliminate distortion due to differential thermal contraction. Beam ports were die-formed.

The demountable rf joint consists of a niobium knife-edge gasket clamped between end plate and cylindrical housing. A large clamping force is required to reduce rf losses and is provided by twenty-four 3/8 inch bolts. Conical spring washers are used to eliminate changes in clamping pressure upon cooling.

The split-ring element was heat-treated by annealing for four hours at 1200C prior to being welded into the cylindrical housing. The housing was given no heat treatment.

Prior to initial tests, all niobium surfaces were electropolished to the extent of removing 50-80 μm of metal.

Resonator Tests

Mechanical Properties

The mechanical properties of the present resonator are excellent: radiation pressure induced frequency shift is $\Delta f/f = 1.3 \times 10^{-6}$ at $E_a = 1$ MV/m, and the vibration induced eigenfrequency shift is $\lesssim 80$ Hz peak to peak under operating conditions. Both effects are reduced a factor of two from the previous design[3] because of the increased rigidity of the resonator housing.

Thermometric Measurements

Thermometry has been used extensively as a diagnostic tool in the present work. Any rf loss into the cylindrical housing, end plates, or demountable joints causes a heat flow through the copper housing into the helium bath and creates temperature gradients which are measured through a network of 15 germanium resistance thermometers attached to the housing.

The thermometric data for the surface of the resonator are interpreted by comparison with current and voltage measurements on an electrical analog, which used resistance paper to model the thermal properties of the copper shell of the resonator. In practice, the magnitude and location of a heat input to the resonator can be determined with accuracies of a few tens of mW and a few inches, respectively.

Resonator Performance

Figure 2 is representative of the performance history to date of the resonator.

In initial tests (Figure 2, curve A), performance was limited by rf losses in the demountable joints at the end plates. The clamping force on the niobium knife-edge gaskets was increased threefold by replacing stainless steel bolts with high tensile strength steel bolts, which were degaussed to eliminate any magnetization.

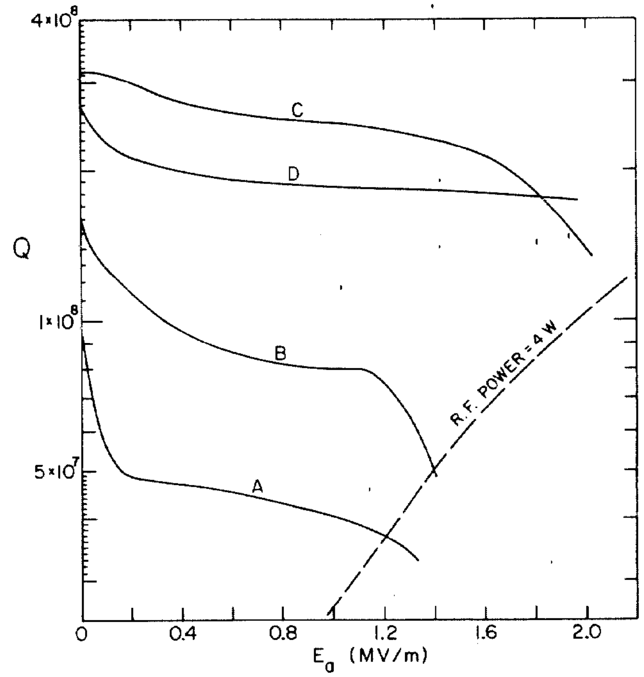

Figure 2. Performance history of the resonator. The curves are labeled in chronological sequence: for details see the text. E_a is the effective accelerating potential for a synchronous particle averaged over the 14 inch interior length of the resonator.

Upon cooling the resonator, the performance shown in curve B was obtained. Although significantly decreased, rf losses were still a factor of three higher than tolerable at high field levels. Thermometric data indicated that less than 15% of the total rf loss occurred in the split ring element and less than 20% in the demountable joints, with most of the rf loss occurring in the niobium-copper material forming the cylindrical housing.

The cylindrical housing was electropolished to the extent of removing 150 μm of metal from the niobium surface. The resonator was then tested with the result shown in Fig. 2, curve C. Thermometric data indicated that rf losses in the cylindrical housing were still the dominant loss term. Electropolishing an additional 150 μm from the housing did not produce a significant change in resonator Q (curve D).

At present, the accelerating field level is limited to 2 MV/m by the onset of a thermal instability manifested by a sudden loss of the rf energy content of the resonator. This phenomenon indicates the presence of a small resistive region or defect in the superconducting resonator which, through joule heating, causes growth of a normal-conducting region when the rf field exceeds some critical level.

Thermometric data indicate that the instability does not occur in the niobium-copper composite but in the split ring element itself. As this region of the resonator is in direct contact with the liquid helium bath, location of the defect by the thermometric method used on the housing was not possible. However, by operating at 1.9K it was possible to observe second-sound pulses caused by the sudden dumping of rf energy into the superfluid He bath. As the velocity of second-sound at 1.9K is ~ 20 m/sec, there is an easily measured time-of-flight over distances of a few cm. By noting the varying time of arrival of the second sound pulse at each of four thermometers, it was determined that the defect is in the stub mounting the split ring to the cylindrical housing. Work is currently underway to repair this defect.

Discussion

Although the thermal instability may prove troublesome to eliminate, it does not represent a fundamental problem for the present design, as it occurs in an element of the resonator (the all-niobium split ring) which has been previously operated successfully[3].

The surface resistance observed in the cylindrical housing of the resonator is nearly an order of magnitude greater than that observed in the "small" sample tests. One of these tests was performed on a section from the same piece of material from which the split ring housing was formed. Since the rf losses in the housing appear uniformly distributed, it seems unlikely that inhomogeneities cause the difference in surface resistance. A possible cause for the difference is that in the course of beam welding the small sample was heated appreciably (to 450-600C) for several minutes. In an experiment now underway, the resonator housing will be given a similar heat treatment.

Conclusions

The present resonator design is characterized by excellent mechanical stability and, at the present level of performance, can provide useful accelerating gradients. However, the performance falls short of the demonstrated capability of the materials and techniques employed and further development is in progress.

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