TWO SUPERCONDUCTING SPLIT-RING ACCELERATING RESONATORS FOR IONS OF VELOCITY 0.045 c AND 0.055 c*

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Abstract

Two superconducting split-ring resonators using the Cu/Pb technology have been built. Previous structures of the same frequency and velocity had their achievable gradient limited by insufficient mechanical stability, and the power dissipation was dominated by losses in the demountable joint between the split-ring and the outer can. These new structures have the split-rings electron-beam welded in the outer can. They also incorporate a new feature: the use of loading arm of non-constant cross section; their diameter being larger at the voltage node than at the drift tube. The increase in mechanical stability should allow them to be operated at accelerating fields limited by the properties of the superconducting surface and not by the mechanical properties of the structure.

Introduction

The first superconducting split-ring resonator utilizing the Cu/Pb technology to be used in an accelerator was the 150 MHz, beta= 0.055 for the Stony Brook heavy-ion LINAC [1], [2]. Because of the Pb plating and polishing procedures used at that time, the split-ring had to be demountable from the outer can, and the demountable joint was the dominant source of power dissipation. Nevertheless, that resonator underwent an extensive series of tests; and its properties, as far as losses, achievable gradient and stability are concerned, proved sufficiently good that it was used as the input stage for SUNYLAC. Simultaneously with the production of the beta=0.055, development work on the beta=0.10 began. The first prototype also included a demountable split-ring [3], but a modification of the Pb polishing procedure allowed the use of a welded split-ring which resulted in a reduction of the power dissipation [4]. Later, a modification of the plating procedure, the doubling of the wall thickness of the loading arms and the use of Pb instead of In gaskets between the end plates and the outer can, produced resonators which were easier to fabricate and achieved higher gradients at a lower power dissipation [5].

While the design of the beta=0.10 has undergone several upgradings, the design of the beta=0.055 has remained frozen for almost 10 years and was already outdated as production was completed. Furthermore, the mechanical stability of the latter proved much worse in the actual accelerator environment than it did during the prototyping stage [6] which probably resulted from an, as yet, not fully understood interaction with the acoustical modes of the He distribution system [7].

This paper will report on a new design for a 150 MHz, beta=0.055 Pb split-ring resonator and for a similar resonator of beta=0.045 (see Fig 1). If the slowest ion that can be accelerated by a resonator is defined to correspond to a transit time factor of 0.4, their velocity would be 0.0355 and 0.0285 for the beta=0.055 and 0.045 resonators respectively. If injected from a 500 kV source, a 9 MV tandem and gas-foil stripping, Sn^{23+} and Au^{26+} would have such velocities with yields of 2 and 1%.[8]

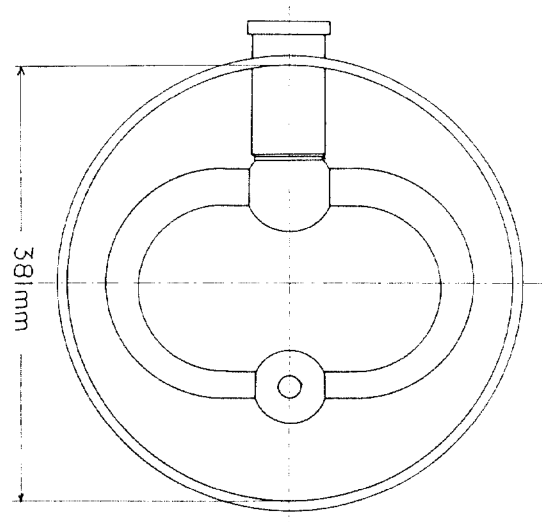

Figure 1 - 150 MHz, beta= 0.045 or 0.055 Cu/Pb resonator.

Resonator design and construction

The split-ring resonator [9] consists of two drift tubes carrying opposite voltages, the displacement currents needed to establish the drift tubes' voltages being carried by a balanced inductive loop. Basically, the split-ring resonator is composed of two strongly coupled, capacitively loaded, quarter-wavelength resonant lines, oscillating in opposite phase. The procedures for designing such superconducting structures have been described elsewhere [10] and were used for these two resonators.

The drift tubes' shape was chosen to minimize the ratio of peak surface electric field and energy gain, and also the loading capacitance. Their location along the beam line was that of zero net electrostatic force in order to minimize the sensitivity to external vibrations. In the final design, the energy gain and peak surface electric field at a drift tube voltage of 1 V, and the loading capacitance was 3.13 V, 93.5 V/m and 6.37 pF respectively for the beta=0.055 and 3.12 V, 120 V/m and 7.87 pF respectively for the beta=0.045.

The calculated accelerating profile was confirmed by bead pulling experiments and is shown in figure 2 at an energy content of 1 J. The transit time factors are shown in figure 3.

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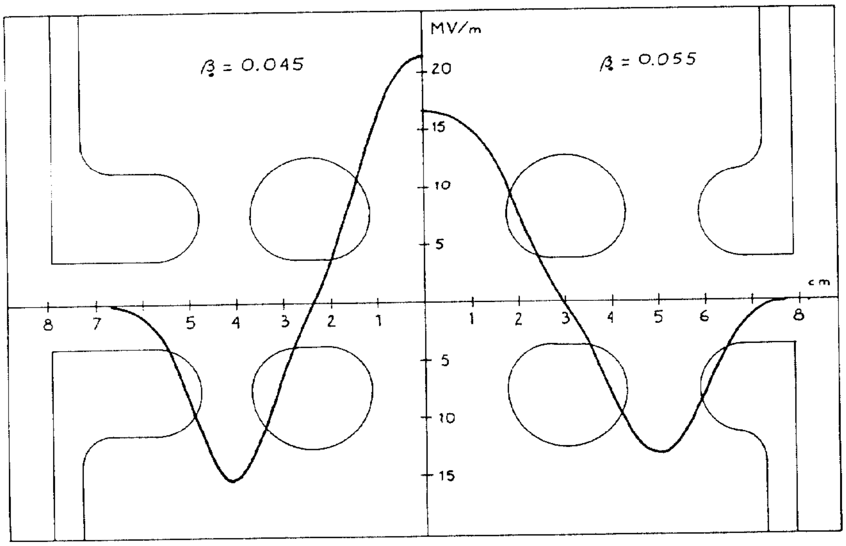

Figure 2 - Electrostatic geometry and field profile at an energy content of 1 Joule for the 0.045 (left) and 0.055 (right) resonators.

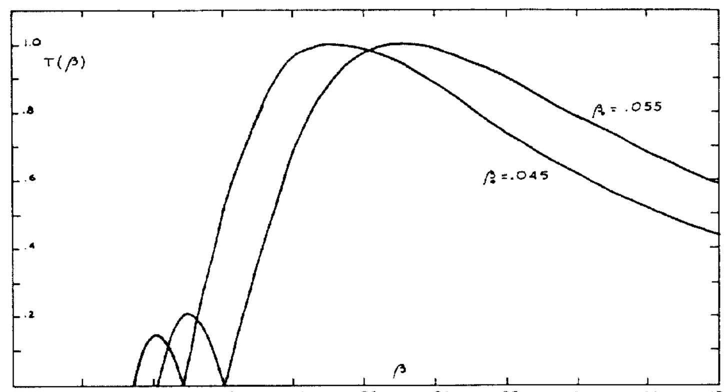

Figure 3 - Transit time factors for both resonators.

Because the chosen frequency, beta and allowable peak surface electric field put a limit on the size of the drift tubes, the diameter of the loading arms at the junctions with the drift tubes was restricted to 0.75 in. Since the mechanical stiffness of the loop is greatly affected by the diameter of the loading arms at the junction with the common stem, it was decided to use a loading arm of non-constant cross section, increasing gradually from 0.75 in. at the drift tube end to 1.25 in. at the shorted end. The initial geometry of each loading arm consisted of a short straight section of 0.75 in. diameter, a concical section, and a short straight section of diameter 1.25 in. Each arm was annealed, electron-beam welded to a drift tube, and bent in a semi-circular shape in one continuous operation. Both loading arms were then electron-beam welded onto the common stem which was subsequently electron-beam welded onto the outer can.

The wall thickness of the loading arms was large enough (0.125 in.) that bending could be accomplished without filler material. Earlier structures used loading arms of much smaller thickness (0.060 in.) and filler material was required to prevent buckling during the bending operation [3]. The increased thickness will also increase the mechanical stability, while the increased diameter in the high current region will reduce the peak surface magnetic field.

The frequencies of the fundamental vibration modes were measured at 90 and 85 Hz respectively for the beta=0.045 and beta=0.055 compared to 55 Hz for the earlier resonator.

With few exceptions, all parts and tooling for both resonators were identical. For the beta=0.045 resonator, the drift tubes were brought closer, and the half-drift tubes on the end plates were made longer (see figure 1). Because, for that resonator, the capacitive loading was larger than for the beta=0.055, the loading arms had to be shorter to achieve the same resonant frequency. This was accomplished by having slightly shorter straight sections on both sides of the conical section.

For both resonators, the difference between measured and calculated frequencies was better than 2%. The properties of both structures are shown in Table I.

Conclusions

Two split-ring resonators of nominal frequency 150 MHz and beta 0.055 and 0.045 have been built and tested at room temperature, they incorporate the latest development in design procedure and fabrication techniques. No prototype resonators were built; the two copper structures which were tested at room temperature will also be Pb plated and cryogenically tested.

Table I

Properties of the beta=0.045 and beta=0.055 split-ring resonators.

Beta	0.045	0.055
Frequency (MHz)	147	153
*Energy gain (MV)	0.140	0.140
*Peak surface E field (MV/m)	5.4	4.2
*Energy content (m J)	20.5	18.7
Geometrical factor (Ω)	20.7	20.3
+Q	6530	6260
+Shunt impedance (MΩ)	6.8	6.8

* At an accelerating field of 1 MV/m

+ Copper, room temperature

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