DEVELOPMENT OF A HEAVY-ION LINAC BASED ON SUPERCONDUCTING INTERDIGITAL ACCELERATING STRUCTURES

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Abstract

Four types of superconducting accelerating structures are being developed for use in a low-velocity positive-ion injector linac planned for ATLAS heavy-ion accelerator. A prototype of the first of these, an interdigital four-gap structure, has been completed and tested at accelerating gradients up to 10 MV/m, corresponding to a maximum surface electric field of 40 MV/m and an effective accelerating potential of 1 MV/resonator. The 48.5 MHz resonant cavity has an active length of 10 cm and is designed for particle velocities in the range 0.007c < v < 0.014c. Prototypes of the remaining three resonator types required for the linac are under construction.

Introduction

Earlier work has suggested the feasibility of a superconducting heavy-ion linac which could be directly injected by an electron-cyclotron-resonance (ECR) positive-ion source on an open-air high-voltage platform.[1,2] A companion paper describes current plans[3] for using the above system to replace the present tandem injector of the Argonne tandem-linac accelerator system (ATLAS).

The proposed linac is based on the fact that short, high-gradient superconducting (SC) accelerating structures can be closely interspersed with short, powerfully focussing SC solenoids. The rapid alternation of radial and longitudinal focussing elements maintains the beam in much the same way as does a Wideroe-type rf structure with quadrupole lenses in the drift-tubes, but with the simplicity and versatility of independently controlled modular elements. Such a linac must accelerate ions in the velocity range 0.007 > $\beta = v/c < 0.06$, which is a factor of six lower than currently possible in a SC linac; thus a substantial extension of present technology is required.

In what follows the very low velocity linac and resonator design are briefly reviewed, then work to date on prototype SC resonators is discussed.

Linac and Resonator Design

The primary technical problem with very low velocity SC accelerating structures is to maintain adequate mechanical stability for the close drift-tube spacing and low rf eigenfrequency required.

To accelerate particles in the velocity range $.007 < \beta < 0.03$ we propose to use three different versions of the interdigital geometry shown in Figure 1. The resonant structure consists of a tapered, coaxial transmission line, shorted at one end and terminated at the other in the capacitive load of a four-gap interdigital structure. The interdigital element is formed by using a forked high-voltage drift tube to straddle a low-voltage counter drift tube and so provide four accelerating gaps.

The choice of number n of accelerating gaps is a trade off between voltage gain per resonator,

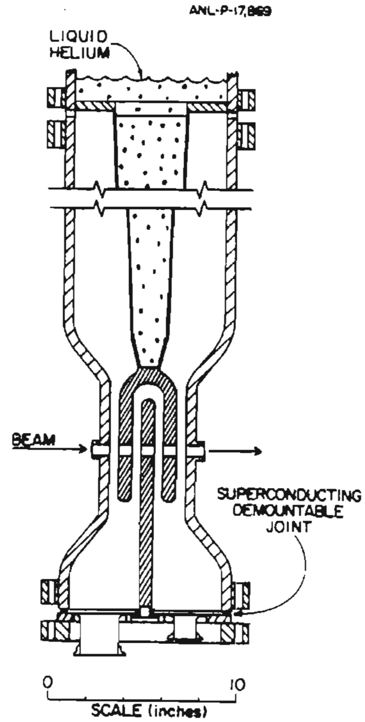

Fig. 1 Cross Section of a 48.5 MHz, 10 cm interdigital resonator. A coaxial, tapered quarter-wave line is terminated in a four-gap interdigital capacitive load. The resonant cavity can accelerate particle with velocities below .01c and has an active length of 10 cm.

roughly proportional to n, and the velocity range accepted by a given resonator type, which is roughly inversely proportional to n. Also, radial defocussing effects become larger with increasing n. For the lower half of the velocity range, where the accelerating gaps are short, we have chosen a four-gap structure.

The upper half of the velocity range can be covered by a single resonator type if a three-gap structure is employed. A possible candidate would be a 48.5 MHz; low-velocity version of the so-called "half-wave" resonant geometry.[4]

Figure 2 shows voltage gain versus entrance particle velocity for the four resonator geometries discussed. The discrete points shown on each curve correspond to the single resonator velocity increments for a uranium beam of charge state 20^+. Thus, a rather modest 22 resonator linac is entirely adequate for ions of any mass. In fact, a very few resonators can form a useful accelerator for the lighter ions because of the higher specific charge available from an ECR source, and also because ATLAS will accept light ions at a lower velocity than for uranium.[4]

A Prototype Superconducting Interdigital Structure

Prototyping was started at the low end of the velocity range since it was felt that the greatest technical problems, particularly with mechanical

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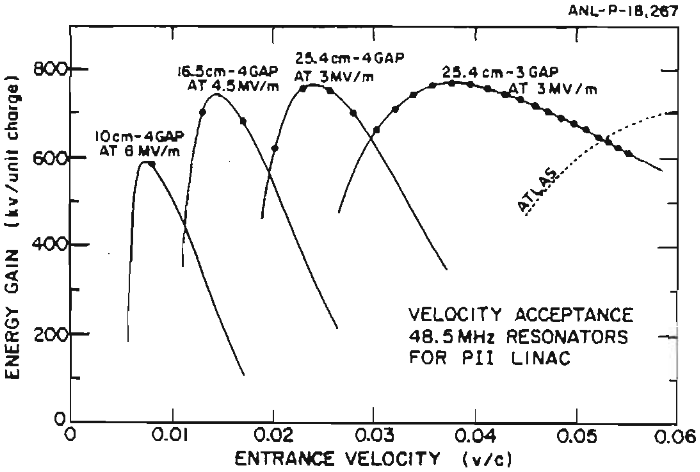

Fig. 2 Voltage gain per unit charge per resonator for four different resonator geometries which can form an injector linac. The discrete points show single-resonator velocity increments for a 20+ uranium beam.

stability, would be encountered at the outset.

Figure 1 shows the cross section of a 48.5-MHz, β = 0.009, four-gap-interdigital accelerating structure. The outer cylindrical housing has an 8-in i.d. and an overall length of 42 in. The tapered center conductor has a diameter of 4 in. at the shorted end and tapers to 2.5-in. diameter just before the drift tube. The forked drift tube straddles a low-voltage counter drift tube, both of 5.5-in. diameter in the transverse plane. The counter drift tube and base plate are demountable, using a previously developed demountable superconducting joint.

The diameter of the drift tubes is substantially larger than needed to shape the fields on the beam axis, and provides a large capacitive load. This shortens the length of transmission line required, and makes a stiff, mechanically stable structure.

The outer housing of the resonator and the counter drift tube are constructed of explosively bonded niobium-copper composite which provides good thermal stability together with high mechanical strength.

The resonator exhibits peak surface electric and magnetic fields of 4 MV/m and 104 Gauss and a total rf energy of 26 millijoules at an effective accelerating gradient E_a of 1 MV/m. E_a is defined as the energy gain per unit charge per unit length for a synchronous particle, averaged over the interior length (10 cm) of the resonant cavity.

Figure 3 shows performance obtained in several tests at 4.2 K. The resonator Q is about a factor of ten lower than for the Argonne split-ring resonators,[5] primarily because the low total rf energy exaggerates the effect of rf losses in the demountable joint. The performance obtained at 4.2 K is substantially better than had been anticipated, with gradients in excess of 6 MV/m for an rf input of 4 watts. The resonator has been operated CW at 10 MV/m at 4.2 K.

The mechanical stability of the structure is excellent. Ambient vibration induced eigenfrequency

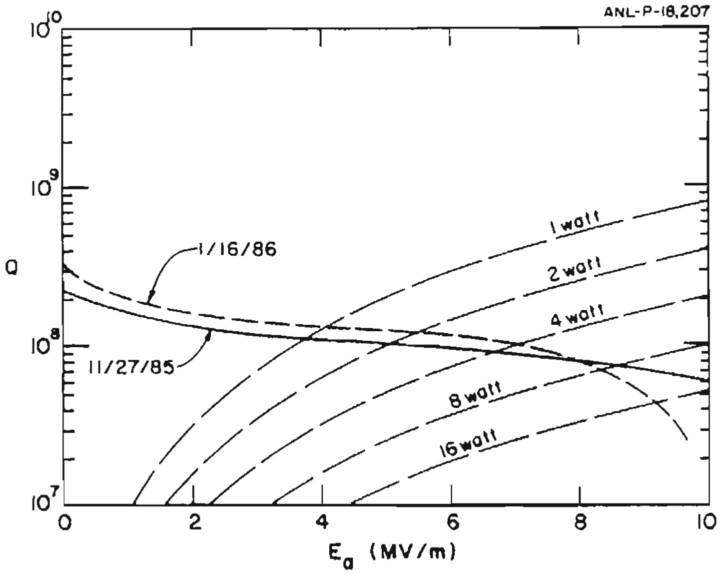

Fig. 3 Resonator Q vs effective accelerating gradient E_a measured at 4.2 K for the superconducting 10 cm interdigital structure. Also shown is the rf power loss at various field levels.

jitter is generally about 200 Hz p-p and was not observed ever to exceed 500 Hz p-p. The radiation-pressure induced eigenfrequency shift was 49 Hz at E_a = 1 MV/m. This level of stability indicates that existing phase-control systems can easily phase-stabilize the resonant cavity.

Discussion and Conclusions

Although several resonant geometries must yet be developed, the successful tests of a prototype superconducting interdigital structure have answered the major outstanding technical questions, and the feasibility of a superconducting interdigital linac seems established.

The prototype 10 cm interdigital structure performs sufficiently well that it will be the only such resonator required even for a full-scale injector for uranium beams. Although we have no plans to make use of the feature, it is interesting to note that at the gradients obtained, the 10 cm structure could accelerate many of the lighter ion species from very low, in fact zero, velocity.

Further development work is in progress. Construction of a prototype 16.5 cm niobium interdigital resonator is well advanced and should be complete in the latter part of 1986. Modeling of the remaining two resonator geometries is in progress and construction of superconducting niobium units will begin this year.

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