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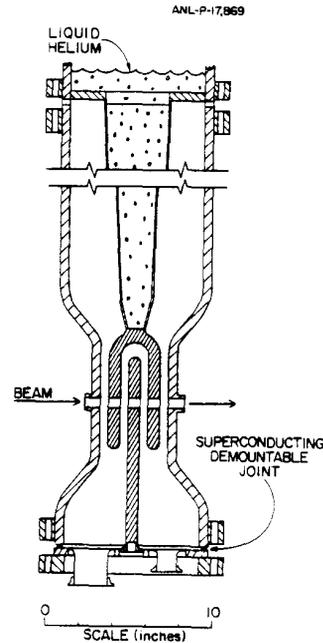
Fig. 1 Cross Section of a 48.5 MHz, 10 cm interdigital resonator. A coaxial, tapered quarter-wave line is terminated in a four-gap interdigital capacitive load. The resonant cavity can accelerate particle with velocities below .01c and has an active length of 10 cm.

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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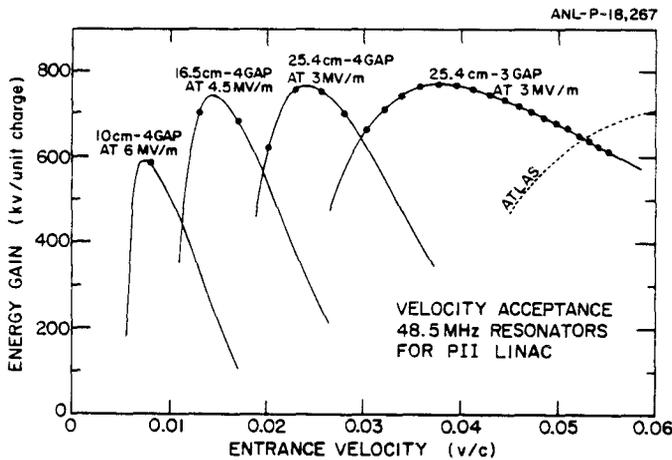ANL-P-18,207

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,
$\beta = 0.009$, 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
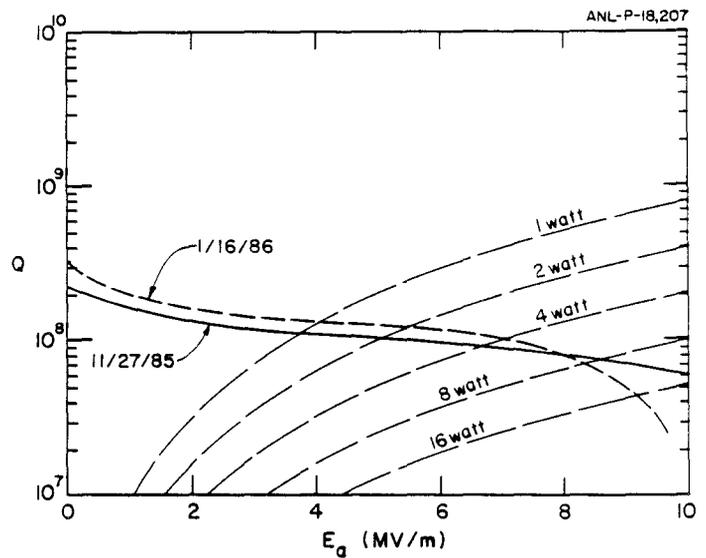excellent. Ambient vibration induced eigenfrequency

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.

Acknowledgement

References

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