DEVELOPMENT OF A VERY-LOW-VELOCITY SUPERCONDUCTING LINAC

Kenneth W. Shepard

Argonne National Laboratory, Argonne, IL 60439 USA

Abstract

Four types of superconducting accelerating structures are being developed for use in a low velocity positive-ion injector linac for the ATLAS heavy-ion accelerator. Prototypes of the first two of these have been tested. The structures are all variants of a quarter-wave line terminated with a four-gap interdigital drift-tube array. The two structure types so far tested operate at 48.5 mHz and have an active length of 10 cm (for the particle velocity = .009c type) and 16.5 cm (for the velocity = .015c type). Effective accelerating fields of 10 MV/m have been achieved with the 10 cm structure, corresponding to an effective accelerating potential of 1 MV. The 16.5 cm structure has been operated at field levels of 6 MV/m, also giving an effective potential of 1 MV. Prototypes of the remaining two resonant geometries are under construction.

Introduction

The planned positive-ion injector for the ATLAS accelerator system consists of an electron-cyclotron resonant (ECR) ion source on a 350 KV platform and a superconducting injector linac designed for particle velocities as low as .008 c.[1,2,3] This low velocity limit is required for acceleration of uranium 20^{+} from the ECR source. The injector linac must accelerate to velocities > .05c to inject efficiently into the existing ATLAS linac.

The injector system is being built in several phases. In the current developmental phase, the ECR source is being built and low-velocity superconducting structures are being developed to be assembled into a 3 MV prototype linac. Even the small prototype system, useful for ions of mass A < 130, will be

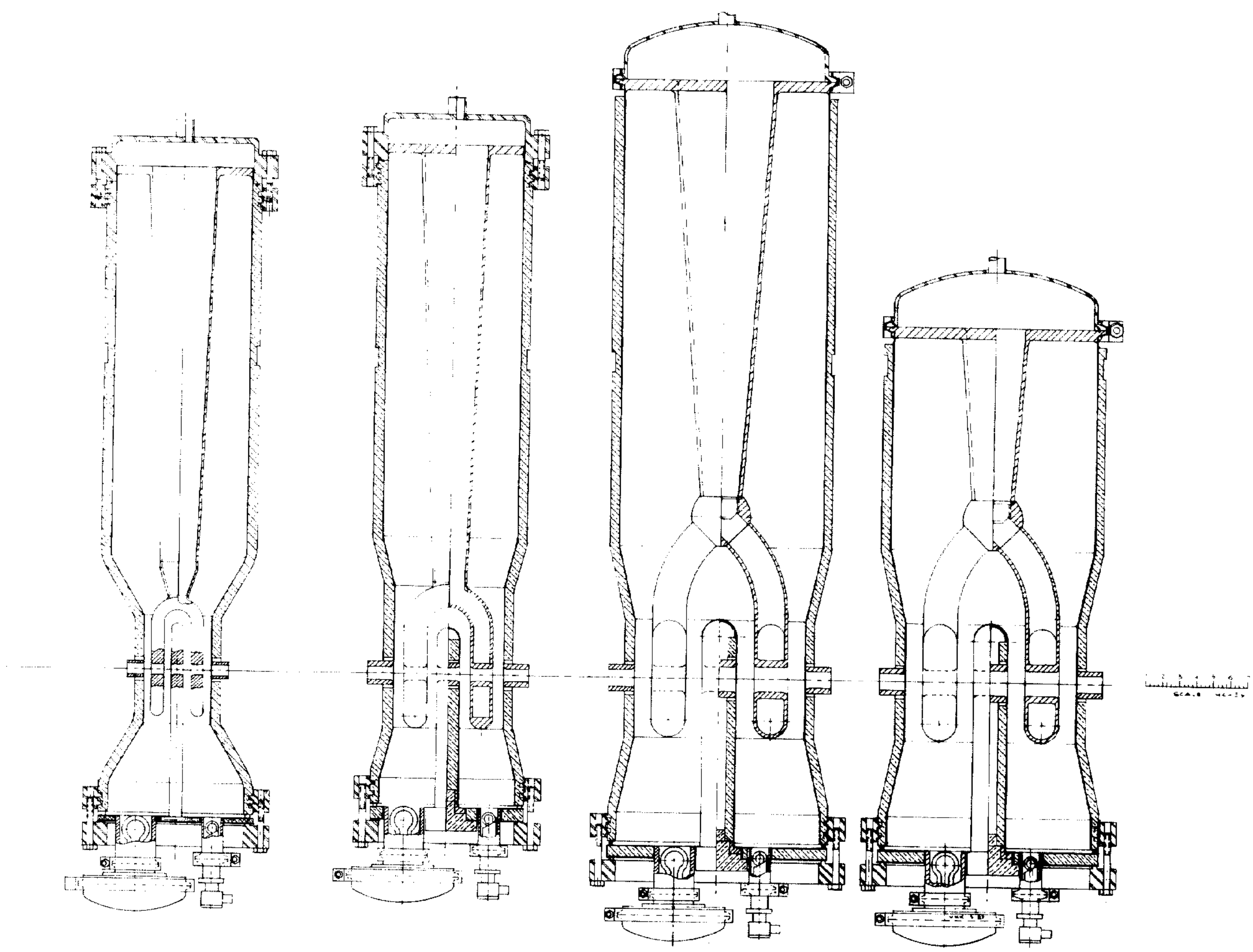

Fig. 1 Cross section of four types of very-low-velocity interdigital superconducting resonant cavities for the ATLAS injector linac. The nomenclature is that, from left to right, the resonator types are labeled I-1 through I-4, in order of increasing particle velocity. Also shown at the bottom of the cavities, are the rf power couplings and fast-tuning systems.

superior to the present 9 MV Tandem as an injector for ATLAS. In later phases, the linac will be expanded to 12 MV, and will provide for the injection of uranium beams into 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 but with the high performance of SC cavities and with the flexibility of independently-controllable modular elements.[1,4]

Linac and Resonator Design

The proposed linac must accelerate ions a factor of six lower in velocity than is the case for present superconducting linacs. The primary technical problem with very-low-velocity superconducting accelerating structures is to maintain good mechanical stability in structures with close drift-tube spacing and low rf eigenfrequency.

The resonant structure chosen consists of a tapered, coaxial, quarter-wave resonant line, terminated at the high-voltage end with the capacitive load of a four-gap, interdigital drift-tube.[2,5] The linac will be an array of such interdigital resonant cavities, which will come in four versions, shown in Figure 1, each covering a portion of the required velocity range. Figure 2 shows the velocity acceptance characteristics of the four structures. The initial linac configuration will consist of one of each type of resonant cavity, plus one additional cavity of the 13 type. The five resonant cavities will provide a total of approximately 3.5 MV of accelerating potential.

In the initial configuration, the linac will be useful for ions with a charge to mass ratio of roughly 1/4 or higher. As the linac is expanded the velocity range will stay the same, but a mix of resonant cavitites of each type will be added (interspersed) to provide for acceleration of heavier ions with a lower charge to mass ratio.

Prototype Resonator Tests

Superconducting prototypes of two of the four structure types have been so far completed and tested. The resonant cavities utilize niobium as the superconductor, and are built using the general methods and techniques developed for the split-ring structures of ATLAS.

The I-1 type prototype has operated repeatedly at accelerating gradients up to 10 MV/m at 4.2k.[4] At 6 MV/m, the prototype provides enough acceleration for uranium 20+ ions that it will be the only unit of its class required even for the 12 MV linac.[5,6] It should be noted that it may be possible to accelerate ions of charge to mass ratio of 1/4 and higher rest with this resonant cavity.

In recent tests, a prototype I-2 type structure has operated stably at accelerating gradients up to 6 MV/m. A gradient of 4.5 MV/m is obtained at the nominal design level of 4 watts of rf input power at a temperature of 4.2k. The accelerating gradient is defined as the energy gain per unit charge for a synchronous particle, averaged over the active cavity length. At 4.5 MV/m, the I-2 structure, with an active length of 16.5 cm, provides 742 kV of effective accelerating potential.

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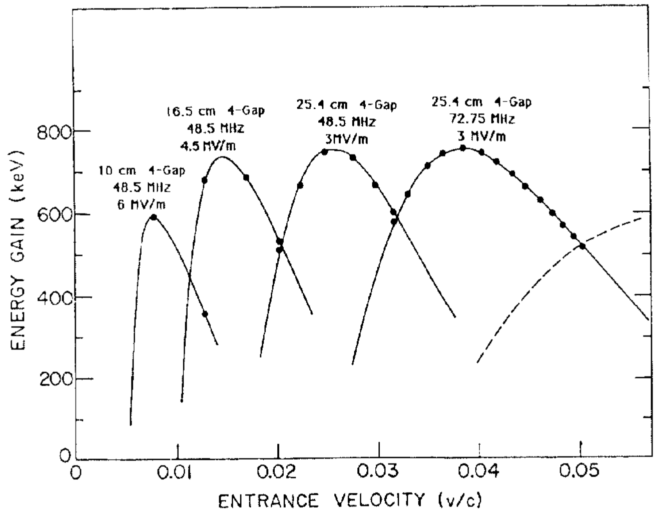

Fig. 2 Voltage gain per unit charge per resonator for four different resonator geometries which can form an injector linac. The discrete points show single-resonator velocity increments for a 20+ uranium beam.

The mechanical stability of both resonator types is excellent. The observed ambient-vibration-induced rf eigenfrequency jitter of a few hundred hertz peak to peak is well within the capability of existing phase control systems.

Superconducting prototypes of the remaining two resonator types, I-3 and I-4 are under construction. I-3 and I-4 are identical except that in I-4 the coaxial line is shortened to increase the resonant frequency from 48.5 to 72.75 MHz. Both units will have an active length of 25 cm, and will be based on a 12 inch O.D. coaxial-line.

Conclusions

A new class of superconducting accelerating structures, suitable for very low particle velocities ($0 < v/c < 0.6$ c) are proving feasible. Accelerating gradients as high as 10 MV/m have been obtained in prototype tests.

These accelerating gradients are substantially higher than the 3 MV/m level originally projected for design of the injector linac. Because of the flexibility of the independently phased array type of linac, if the increased performance proves typical, it can be immediately exploited to provide increased performance of the injector system.

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