SUPERCONDUCTING LOW-VELOCITY LINAC FOR THE ARGONNE POSITIVE-ION INJECTOR

K. W. Shepard, P. K. Markovich, G. P. Zinkann,
B. Clifft, and R. Benaroya
Argonne National Laboratory
Argonne, IL 60439

Summary

A low-velocity superconducting linac has been developed as part of a positive-ion injector system, which is replacing a 9 MV tandem as the injector for the ATLAS accelerator. The linac consists of an independently phased array of resonators, and is designed to accelerate various ions over a velocity range $.008 < v/c < .06$. The resonator array is formed of four different types of superconducting interdigital structures. The linac is being constructed in three phases, each of which will cover the full velocity range. Successive phases will increase the total accelerating potential and permit heavier ions to be accelerated. Assembly of the first phase was completed in early 1989. In initial tests with beam, a five-resonator array provided approximately 3.5 MV of accelerating potential and operated without difficulty for several hundred hours. The second phase is scheduled for completion in late 1989, and will increase the accelerating potential to more than 8 MV.

Introduction

The positive ion injector (PII) for the ATLAS accelerator system consists of an electron-cyclotron resonance (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]. The low velocity is required for the acceleration of uranium 20+ ions from the ECR source. The injector linac must accelerate ions to velocities >.05c to inject efficiently into the ATLAS linac.

A general discussion of the overall system and details of performance in initial beam tests are the subject of another paper in these proceedings [4]. The present paper focuses on the superconducting linac portion of the injector system.

The linac is formed from short, high-gradient superconducting (SC) accelerating structures closely interspersed with short, powerfully focusing SC solenoids. The rapid alternation of radial and longitudinal focusing 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.

Superconducting Resonators

For this application, SC accelerating structures were developed which accelerate particles a factor of five lower in velocity than had previously been possible with SC RF devices. To accomplish this, four different geometries of SC interdigital accelerating structure were developed, as shown in Figure 1. Four types were necessary to cover the required velocity range.[3]

The interdigital structure consists of a tapered, coaxial quarter-wave resonant line terminated with a bifurcated drift-tube. With a counter-drift tube, the structure has four accelerating gaps. The structure can efficiently accelerate particles with velocities within about ± 20% of the optimum velocity.

Table I lists some properties of the four resonator geometries. Although the resonator geometry differs substantially from the earlier developed split-ring structures used in ATLAS, many of the same construction techniques could be used: in particular, a SC RF demountable joint to mount the counter-drift-tube, and an explosively-bonded Nb-Cu composite for the outer housing of the resonant cavities.

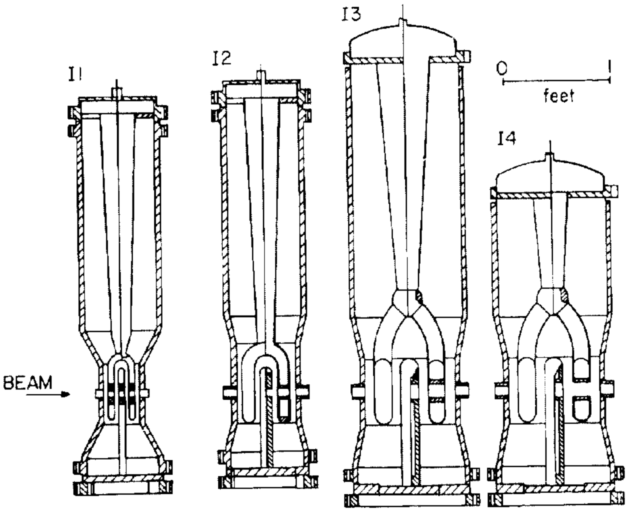

Fig. 1 Cross sections of the 4-gap interdigital superconducting resonators for the injector linac. The first three units operate at 48.5 MHz and the fourth at 72.75 MHz.

A primary problem in matching to very low particle velocities with SC structures is mechanical stability. For the structures discussed here, matching lower velocities is accomplished either by reducing the spacing between drift tubes, or by going to lower frequencies by lengthening the transmission line. The first method increases the RF eigenfrequency shift caused by mechanical motion of the drift-tubes, and the second decreases the rigidity of the structure and increases the ambient microphonic-induced mechanical motion.

The SC resonators were designed to be as mechanically stable as possible, primarily by using a massive coaxial quarter wave line as the base geometry. Also, a new fast-tuning system of increased capacity, discussed elsewhere in these proceedings[5], was developed to insure the phase control of the interdigital structures.

CH2669-0/89/0000-0974$01.00©1989 IEEE

Linac Cryostat

The vertical height (52 inch max.) of the interdigital structures required that the linac cryostat be completely redesigned from the earlier ATLAS cryostat for split-ring resonators.

The PII linac cryostat module, shown in Fig 2, starts with a 7 x 3 x 10 foot rectangular-box vacuum shell, lined with a 77 K heat shield of 1/8 inch polished aluminum. No super-insulation is used, since the cryostat vacuum and the interior resonator vacuum space are in common, requiring a high level of cleanliness.

Each cryostat module houses six SC resonant cavities and associated SC solenoid focusing elements. The focusing solenoids are 1 inch bore, 80-kG units, for which windings are commercially available.

Several features were carried over from the ATLAS cryostat design. A LN_2-cooled cable manifold carries all of the RF and thermometric cabling, which is thus well-anchored thermally before being distributed to the resonant cavities. Also a cryogenic circuit separate from the main LHe reservoir links a series of heat exchangers coupled to each resonator and solenoid. These heat exchangers greatly speed the cool-down and warm-up processes.

A primary difference from the ATLAS system is that all parts of the SC cavities can be cooled by static boiling of LHe, so that forced-flow cooling of the resonators is not required.

In final form, the injector linac will consist of three cryostat modules housing 18 resonant cavities.

Initial Tests

The first phase cryostat module has been assembled with five interdigital structures and five SC solenoids. The resonant cavities are one each of the four types plus a second resonator of the third (I3) type. This array should be sufficient to accelerate ions of mass < 100 for injection into ATLAS.

The first module has been pumped down and successfully cooled in an initial tests. These tests culminated in operation with beam in late February and early March of this year.

While the linac is still in its shakedown mode, and present results are preliminary, performance to date has been satisfactory in all respects.

The static heat leak to 4.6 K was observed to be 20 - 25 watts in the loaded cryostat module. While this result is adequate, it is about 10 watts higher than was hoped for: the cause has not yet been diagnosed.

It had been observed in off-line tests that multipacting in the SC interdigital structures was somewhat stronger than in the ATLAS split-ring resonators. In on-line operation the difference was more pronounced: more than three days of RF conditioning was required to process through multipacting barriers in some of the interdigital

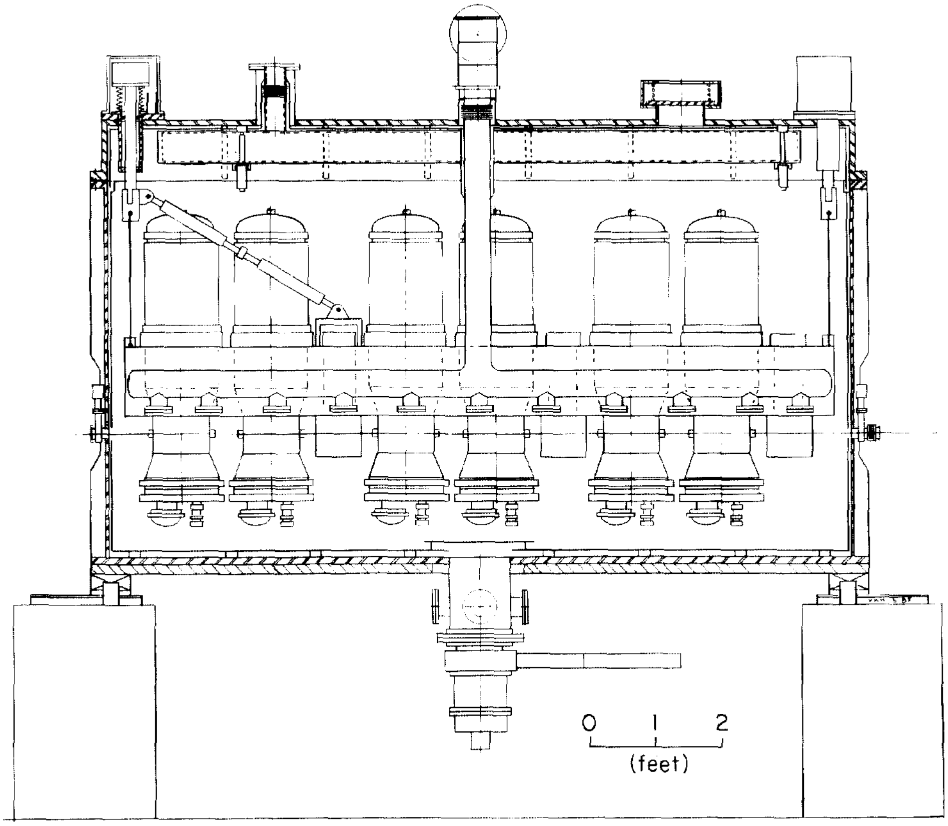

Fig. 2 Section of an injector linac cryostat module with six 13-class resonators (see text) installed. For each pair of superconducting resonators, there is a superconducting solenoid focusing element.

Table I

Some Characteristics of Four Superconducting Niobium Interdigital Accelerating Structures

UNIT	MATCHED VELOCITY	FREQUENCY	EFFECTIVE LENGTH	ACCELERATING FIELD* OFF-LINE	ON-LINE
I1	.009	48.5 MHz	10 cm	6.2 MV/m	4.4 MV/m
I2	.015	48.5	16.5	4.5	3.0
I3	.025	48.5	25.4	4.1	3.7
I4	.037	72.75	25.4	3.9	4.1

*For approx. 4 watts RF input to 4.6 K.

structures. This is about a factor of ten more time than required for the ATLAS modules. Once conditioned, however, the resonators operated stably for the entire two-week test period.

While the time-to-condition is not a fundamental problem, it could be an annoyance when rapid access to the cryostat is called for, since the multipacting levels are re-established if the resonators are heated to room temperature.

Microphonic-induced RF eigenfrequency variations were, with one exception, well within the capacity of the fast-tuning systems. The exception was that, initially, vibration of the I2 unit was slightly beyond controllable limits - the source of microphonics was found to be a helium compressor for the refrigeration system located in another area of the building. Vibration-isolating the compressor eliminated this problem.

The accelerating gradients obtained with beam were entirely satisfactory. The units were operated continuously for 200 hours at 4.4, 3, 3.7, 2.3, and 4.1 MV/m for the five units in sequence. At these field levels, the linac provides 3.5 MV of effective accelerating potential.

The fourth unit was limited in field for the trivial reason of an incorrect coupling of its fast-tuning system, which should be easily corrected. Even including this unit, the average accelerating gradient and the total accelerating voltage obtained in this initial test are slightly higher than the early projections of performance for this machine.[2]

Operation of the linac was characterized by excellent reliability and stability. The machine ran for the better part of a week with virtually no operator intervention.

Future Plans

In the last half of 1989, the phase one PII will be used at least part of the time as the injector for normal operation of ATLAS. Assembly of the second cryostat module should be complete in late 1989. Installation of this module will increase the injector linac to 8 MV and complete the second phase of the injector. The following year a third and final cryostat module will be built which will bring the injector up to 12 MV and enable the acceleration of uranium beams.

Acknowledgment

This research was supported by the U.S. Department of Energy, Nuclear Physics Division, under contract W-31-109-ENG-38.

References

1. L. M. Bollinger and K. W. Shepard, in Proc. 1984 Linear Accelerator Conf., Seeheim, Fed. Rep. Germany, May 7-11, 1984, p217 (1984).

2. L. M. Bollinger, R. C. Pardo, and K. W. Shepard, in Proc. 1986 Linear Accelerator Conf., Stanford, California, June 2-6, 1986, p266 (1986).

3. K. W. Shepard, in Proc. 1987 IEEE Particle Accelerator Conf., Washington, D.C., March 16-19,1987, p1812 (1987).

4. L. M. Bollinger, P. K. Den Hartog, R. C. Pardo, et al., in the proceedings of this conference.

5. J. M. Bogaty, B. E. Clifft, et al., in the proceedings of this conference.