Superconducting RF Development at ATLAS

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Introduction

The ATLAS superconducting heavy-ion linac began operation in 1978 and has operated nearly continuously since that time, while undergoing a series of upgrades and expansions, the most recent being the "uranium upgrade" completed earlier this year and described below.

In its present configuration the ATLAS linac consists of an array of 64 resonant cavities operating from 48 to 145 MHz, which match a range of particle velocities $.007 < ß = v/c < .2$. The linac provides approximately 50 MV of effective accelerating potential for ions of $q/m > 1/10$ over the entire periodic table. Delivered beams include 5 - 7 pnA of $^{238}U^{39+}$ at 1535 MeV. At present more than 10^6 cavity-hours of operation at surface electric fields of 15 MV/m have been accumulated.

Superconducting structure development at ATLAS is aimed at improving the cost/performance of existing low velocity structures both for possible future ATLAS upgrades, and also for heavy-ion linacs at other institutions. An application of particular current interest is to develop structures suitable for accelerating radioactive ion beams. Such structures must accelerate very low charge to mass ratio beams and must also have very large transverse acceptance.

ATLAS Uranium Upgrade

The ATLAS uranium upgrade, or positive-ion injector system (PII), has been extensively described elsewhere [1,2,3,4]. PII consists of an ECR ion source on a 350 KV high voltage platform serving as the injector for a 15 MV, very-low-velocity superconducting linac, which is optimized for the acceleration of U^{26+} ions.

In developing PII, a primary technical challenge was to maintain rf phase control of the very low frequency (48 MHz) resonators. The low frequency is required to match very low particle velocities while providing good transverse acceptance and high beam quality [5]. This was enabled in two ways: first, the resonator design emphasized mechanical stability, and second, the ATLAS variable reactance fast tuning system was upgraded for this project. The resulting PIN-diode based tuning system provides a 30 KVA reactive tuning power capability [5].

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Resonator Type	Active Length	No. Resonators	Accel. Field
I1 Four-gap	10.16 cm	1	4.5 MV/m
I2 Four-gap	16.5	2	3.9
I3 Four-gap	25.4	5	3.5
I4 Four-gap	25.4	10	3.7

Table I - Average accelerating fields obtained in operation of the PII linac superconducting resonant cavities with beam. Peak surface electric fields are approximately five times the accelerating field level.

The linac is an eighteen resonator array of four different types of interdigital accelerating structure (see Figure 1). The full system has been operational since early 1993, and the design accelerating field of 3 MV/m has been substantially exceeded, as is shown in Table I.

Figure 2 shows a six-resonator array from one of three cryostat modules for the PII linac. The over-all system has proven reliable and easy to maintain and align, and exhibits exceptional beam quality [4].

Niobium Coaxial Quarter-wave Cavities

Figure 3 shows a cross section of a pair of coupled coaxial quarter-wave resonant cavities being developed at Argonne National Laboratory in a collaborative project with the Centre for Nuclear Science, New Delhi, India [6,7]. The resonator design is intended for use in a superconducting linac in New Delhi [6,8]. The project goal is to develop a high-performance structure based on the coaxial quarter wave line geometry (with a single drift-tube) while minimizing costs for the resonant cavities and associated equipment. Several novel features are incorporated into the design.

In distinction to the resonant cavities used heretofore at ATLAS, explosively bonded niobium copper composite material is not being used for the outer walls of the coaxial structure. The structure is instead formed of 1/16 and 1/8 inch niobium sheet. The design has been modeled in copper to verify that walls this thin give adequate mechanical stability [6].

Each coaxial cavity is contained in a stainless steel jacket, which is penetrated by ports for the beam and also for rf coupling. Each port employs an explosively-bonded niobium-stainless steel weld-transition flange. The jacket is welded in place after chemically polishing the niobium structure.

The prototype structures are intended to explore the possibility of operating the cavities in strongly-coupled pairs. Coaxial quarter-wave resonators are two-gap accelerating structures and are relatively short, so that a large number of independently-phased cavities is required for a linac. Strongly coupling cavities can reduce the number of independently-phase elements, but at the cost of reducing the range of useful velocity acceptance for the elements. Coupling two cavities splits the accelerating rf eigenmode into two modes, each of which covers a portion of the full velocity range of a single cavity. Enabling the use of either the symmetric or anti-symmetric mode would permit using coupled pairs with little loss in velocity acceptance. This would reduce the number of independently phased elements required for a linac.

At the high-voltage end of each coaxial cavity, the outer housing consists of a short niobium "bellows" assembly to provide cavity tuning capability of several hundred kiloherz. Such a large tuning range is needed only if the cavities are operated in strongly coupled pairs, in order to tune either the symmetric or the antisymmetric mode to the linac operating frequency [6,7].

Construction of two prototype niobium cavities of this design is in the final stages, with initial cold tests expected in early 1994.

Superconducting RFQ Development

Figure 4 shows a cross-section of a superconducting 194 MHz RFQ resonant cavity currently being constructed of niobium [10,11]. In an earlier experiment, cw peak surface electric fields above 100 MV/m were achieved in an ATLAS split-ring resonant cavity modified to include a short (6 cm) RFQ vane structure [9]. The structure discussed here is intended as a next development step with the objectives:

1. Determine the electric field limits in a niobium RFQ of useful length (50 cm).

2. Determine the difficulty of achieving sufficient mechanical stability in a superconducting RFQ to permit rf phase stabilization in low-beam-current applications.

3. Permit testing with beam at the ATLAS heavy-ion facility.

Table II shows some of the electrodynamic properties of the resonant geometry chosen. Note that, although has four-fold rotation symmetry, the dipole-quadrupole mode separation is large, insuring ample mechanical tolerances (.005 inch) compatible with the need to heavily chemically polish the superconducting niobium surface.

The simplicity of the geometry permits fabrication by assembling eight identical simple "T" sections: in this way, tooling and fixturing costs are kept small. Also since peak surface field, rather than shunt impedance, is the primary design constraint, the rod and post structure can assume massive proportions, ensuring good mechanical stability.

A copper model of the structure has been built and tested, and construction of a niobium prototype is well-advanced with cold tests expected in the first half of 1994.

Parameter	Calculated (MAFIA)	Measured Value
Quadrupole Mode	199.5 MHz	198.6 MHz
Dipole Modes	215.6 MHz	214.9 MHz 214.2 MHz
Surface B_{peak}^*	702 Gauss	680 Gauss
Surface E_{peak}^*	120 MV/m	-
RF Energy*	6.1 Joule	10.1 Joule

Table II - Numerical and model measurement results for some electrodynamic properties of the four-fold symmetric rod and post RFQ resonator geometry chosen.
* Normalized to an inter-vane voltage of 465 KV.

Other Development Activities

There is currently interest in the astrophysics and nuclear physics communities in establishing a national radioactive beam facility [12]. Superconducting ion linacs have several properties that make them the technology of choice for the acceleration of radioactive beams [13]; these include very large transverse acceptance, cw operation, and superb beam quality.

A new technical challenge with radioactive beams will be to accelerate heavy ions of very low charge state in a cost-effective manner. To meet this challenge it would be desirable to reduce the cost of superconducting structures, particularly at very low particle velocities. Also, to maximize transverse acceptance and beam quality and to avoid the use of normally-conducting structures, it would be desirable to extend the allowed frequency range for phase-stable operation of a superconducting structures from the presently achieved 50 MHz downward to 25 or even 12 MHz. While some of these issues are addressed by the projects discussed above, two further development efforts have been initiated at ATLAS:

1. Design of an extended interdigital accelerating structure. By putting more drift-tubes in a resonant cavity, the effective accelerating voltage per cavity, which dominates linac costs, can be increased by factors of two or more.

2. Development of fast-tuning systems of increased capability and also development of methods of mechanically stabilizing low frequency structures.

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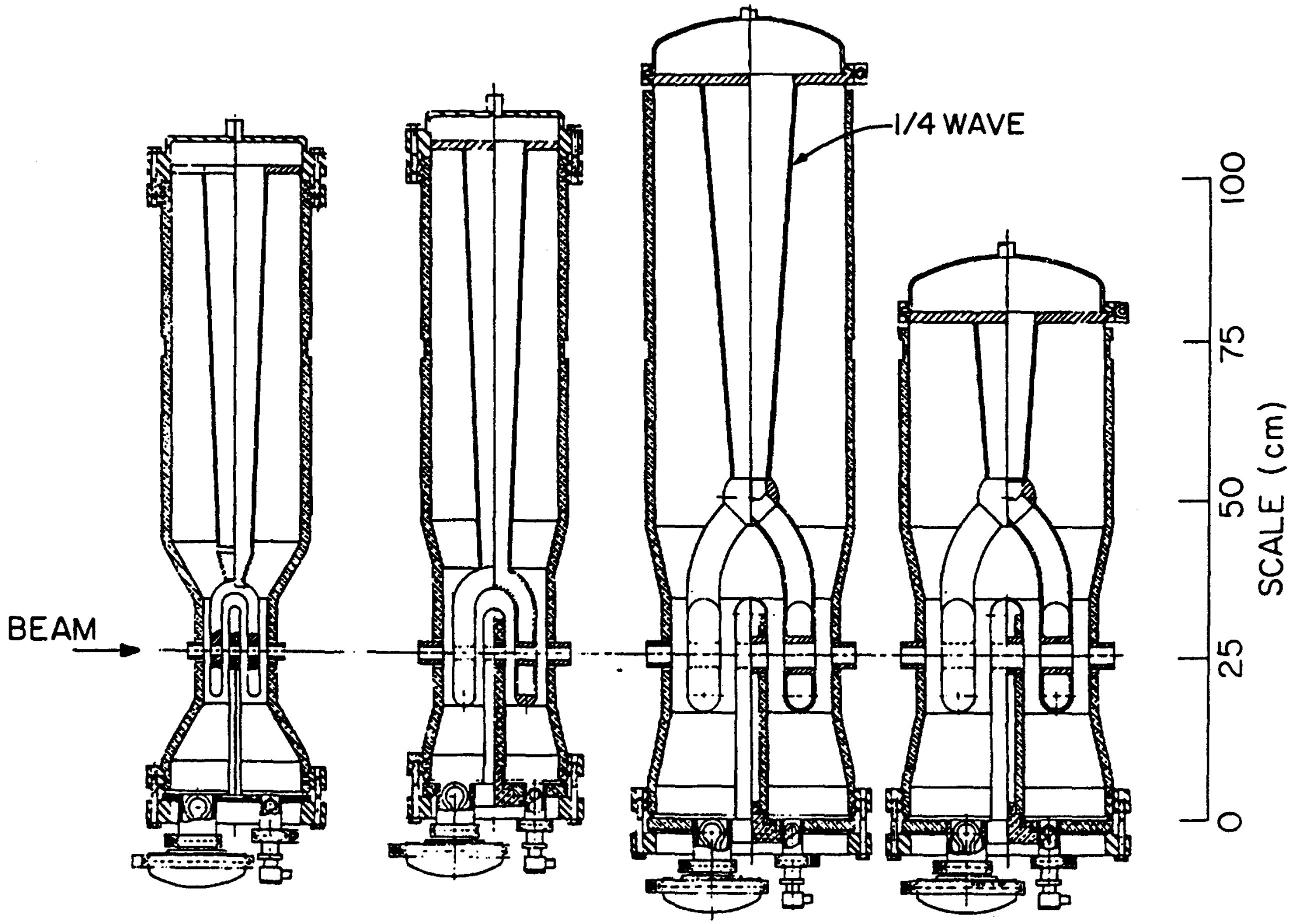

β	0.009	0.016	0.025	0.037
L_a (cm)	10.2	16.5	25.4	25.4
f (MHz)	48.5	48.5	48.5	72.75

Figure 1 - Low-velocity accelerating structures for the PII linac

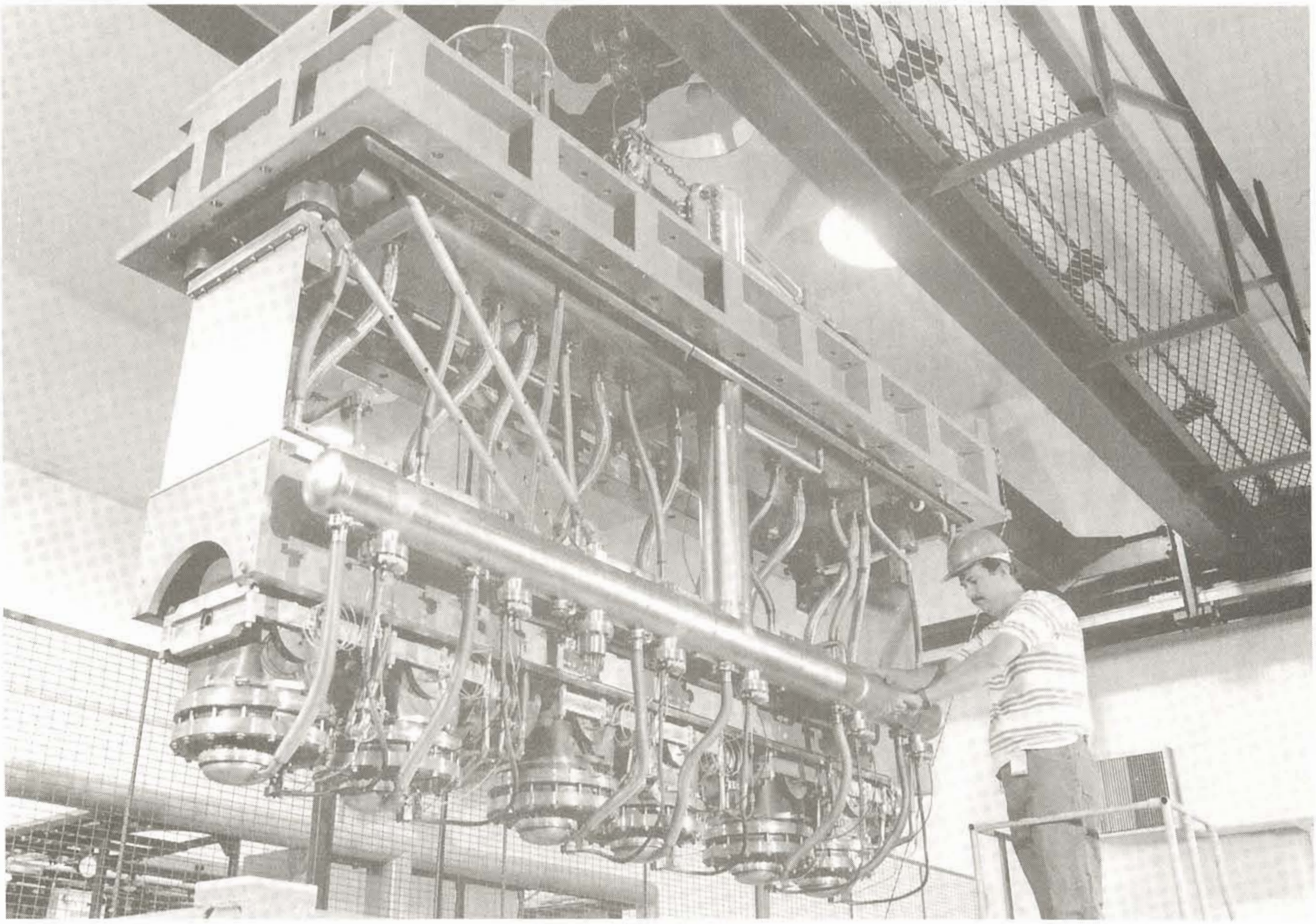

Figure 2 - A six-resonator array for the third cryostat module of the PII linac

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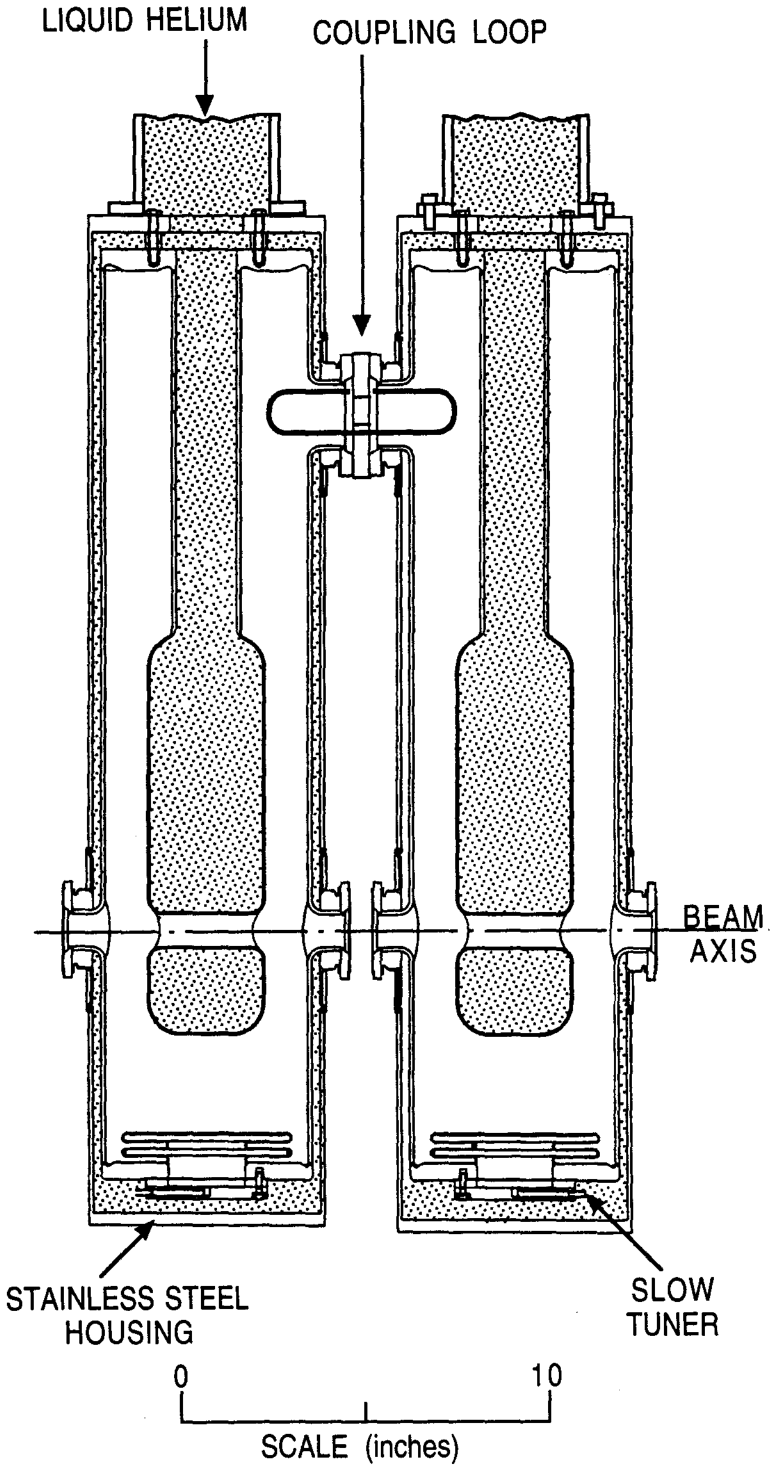

Figure 3 - Cross Section of a pair of coaxial quarter-wave line cavities

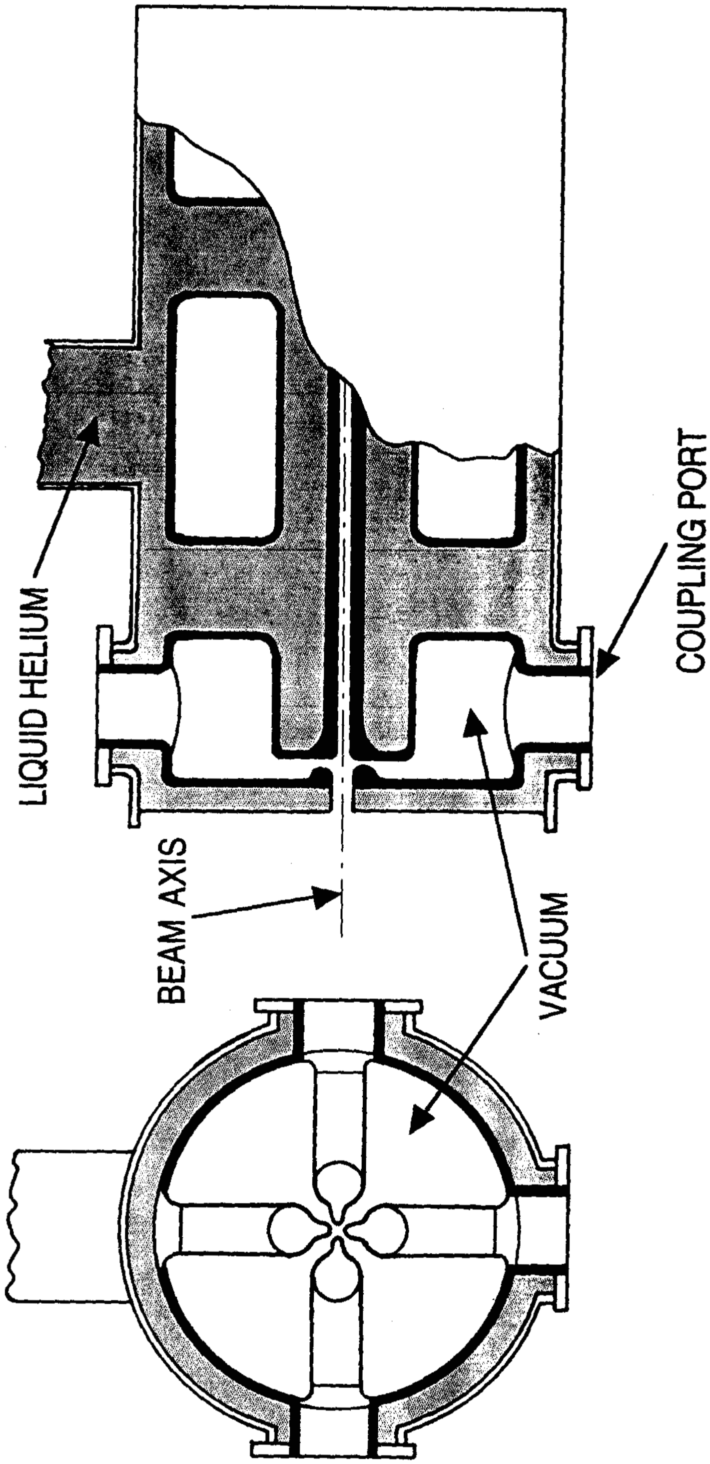

Figure 4 - Cross section of the four-fold symmetric rod and post RFQ structure. Overall length is approximately 50 cm.