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STATUS OF THE STONY BROOK SUPERCONDUCTING HEAVY-ION LINAC*

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Summary

The present status of the Stony Brook Superconducting Heavy-Ion Linear Accelerator is described, with emphasis on recent operational results with a prototype unit of the accelerator. The basic LINAC elements are independently-phased lead-plated copper split-loop resonators operating at 151.7 MHz and optimized for velocities of either $\beta=v/c=0.055$ or $\beta=0.10$. Resonators are grouped in units of either 4 low-β or 3 high-β resonators in compact cryostat modules separated by room-temperature quadrupole-doublet lenses. The LINAC consisting of 4 low-β and 7 high-β modules injected with heavy ions of mass A≃16-100 from the Stony Brook FN tandem will produce an additional energy gain of ∿18 MeV per unit charge with a total heat dissipation at 4.5K of <300 Watts.

In recent tests with low-β prototype units, individual resonators were operated continuously at accelerating gradients in excess of 3.5 MV/m, and were phase and amplitude stabilized at 3.0 MV/m using 175 Watts of RF power. Helium-temperature dissipation at 3.0 MV/m is ∿8 Watts after helium-gas conditioning. The prototype low-β module was used to accelerate a 30 Mev $^{16}O^{5+}$ beam to ∿35 MeV.

I. Introduction

A Superconducting Linear Accelerator for Heavy-Ions will be constructed at Stony Brook to extend the useful mass range of the existing FN tandem Van de Graaff to A ≃ 100. The anticipated LINAC output energy at an accelerating gradient of 2.5 MV/m will range from ∿12 MeV/A for oxygen ions to ∿5 MeV/A for bromine. This performance is comparable to the output energy of a 20-25 MV tandem. The LINAC is based on the lead-plated copper split-loop structure developed at Caltech in the period 1970-1975 and first tested in-beam at Stony Brook in 1976 (see Ref. 1).

The overall LINAC design has been extensively discussed in earlier publications and reports.[2-4] The present status of the project is at the advanced prototype stage, with construction of the first production-model accelerator module well underway. The present report emphasizes recent operational results with the prototype low-β resonator and the prototype low-β module containing four independently-phased resonators. The single resonator buncher will be used to produce psec pulses for nuclear physics experiments while construction of the full LINAC is underway.

II. LINAC Design and Performance

Characteristics of the proposed LINAC are summarized in Table I. The critical design choices are the selection of lead-plated copper as the resonator material, the selection of a relatively high frequency of ∿150 MHz, the use of a modular cryostat structure with interspersed room-temperature lenses, and the use of pool-boiling helium for cooling. The relatively high frequency in turn makes feasible phase and amplitude stabilization by direct RF feedback under microprocessor control.

The LINAC contains two types of split-loop resonators, optimized for velocity $\beta=0.055$ and $\beta=0.10$, respectively. Performance of the low-β resonator is well

Table I. LINAC Characteristics

Operating frequency:	151.7 MHz
Resonator configuration:	Split-loop made from Pb-plated copper
Low-β resonators:	$\beta_o=0.055$, inside length 14 cm, can diameter 35 cm
High-β resonators:	$\beta_o\approx0.10$, inside length* 21 cm, can diameter 38 cm
Total number of resonators:	16 low-β, grouped in modules of 4 21 high-β, grouped in modules of 3
Resonator cooling:	Pool boiling helium at 4.5° K
Maximum accelerating gradient obtained:	3.8 MV/m
Typical losses**	5 W at 2.5 MV/m, 8 W at 3.0 MV/m
Energy gain per resonator:	at 2.5 MV/m: 350 keV/charge (low-β) 635 keV/charge (high-β)
Transverse focussing:	Room temperature magnetic quadrupoles, 4 kG/cm
Cryostat length:	110 cm
LINAC length:	1700 cm for 11 modules
Maximum energy gain:	18 MeV/charge at 2.5 MV/m
He consumption at 2.5 MV/m:	288 Watts
Total installed refrigeration:	400 W at 4.5 K, with 1000 ℓ in storage
Phase control:	Direct RF feedback, phase error ±0.1°
Total RF power:	<12 KW

*Lengths do not scale as β because of different end-flange design.

**Achieved consistently with low-β resonators.

established, as described below, while that of the high high-β resonator as yet can only be estimated by scaling. Assuming losses in the high-β resonator are 50% greater than those in the low-β resonator for the same accelerating gradient, the total refrigeration requirement at 2.5 MV/m is ∿300 W. Even for high-β resonator losses twice those of the low-β units, the total heat load of 340 W is less than the refrigeration capacity of 400 W which will be installed.

III. The low-β Resonator

Figure 1 shows the assembly of one of the $\beta=0.055$ 150 MHz split-loop resonators. The split-loop is fabricated from OFHC copper pieces joined by electron-beam welds. In operation the hollow loop base and loop tubes are filled with liquid helium which cools by conduction the solid copper drift tubes and resonator can. The various resonator components are first mechanically and then electro-polished, plated with an ∿15 micron thick layer of lead, and finally given a light chemical polishing which removes ∿5 microns of the lead.[5] The split-loop [resonator end-plates] is demountably joined to the resonator can by Sn-In [pure In] wire gaskets, respectively. The plated resonators are assembled and handled in the open air for periods of many hours with no apparent deleterious effects. The assembled resonators are kept in a nitrogen gas atmosphere until evacuation of the cryostat. With this procedure and a modest bakeout at ∿50°C before cooldown, conditioning the resonator through multipactor levels to the highest field requires only a few minutes. The resonator processing is further facilitated by a variable-coupling arrangement which employs a copper folded-line resonator at 77 K whose frequency can be varied by a remotely-operated stepping-motor. A second stepper-motor at 77 K operates a squeezing mechanism which allows the resonator frequency to be varied by ∿50 kHz in steps of a few Hz.

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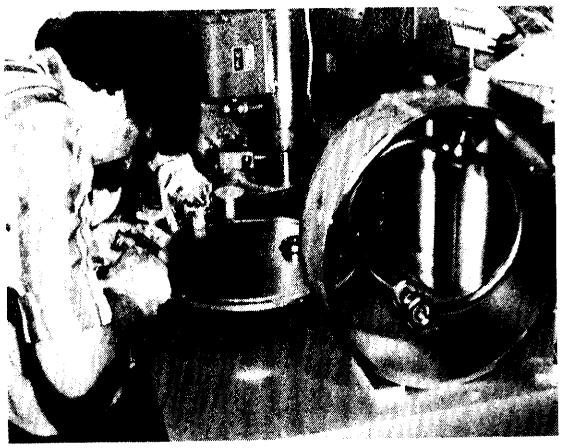

Figure 1. Assembly of a low-β resonator.

Table II summarizes the performance of the low-β resonators, as determined from extensive tests with the first five resonators of the final design. The accelerating gradient referred to here is the actual energy gain per unit charge for the optimal-velocity particle, averaged over the 14 cm overall inside length of the resonator. At 3.0 MV/m accelerating gradient the peak surface electric and magnetic fields are 19 MV/m and 270 G, respectively. The resonators typically have 4.2 K losses of 3 W at 2.0 MV/m and 5 W at 2.5 MV/m, increasing rapidly at higher gradients due to field emission. After a modest amount (up to one hour) of He-gas conditioning, the resonators operate at sustained gradients of ≳ 3.5 MV/m and have ∿8 W dissipation at 3.0 MV/m. Exceptional cases of higher resistive losses are attributed to faulty lead surfaces and can be corrected by re-plating.

In the original design of the low-β resonator the separation between the accelerating and non-accelerating (symmetrical or "push-push") modes was only a few hundred kHz for the loop configuration (which is the desired operating point) in which the axial drift-tube forces are equal and the frequency of the accelerating mode reaches a maximum. In 1978 the loop bases of the five prototype low-β resonators were modified to raise the frequency of the non-accelerating mode by ∿5 MHz. Figure 2 shows the results of bead tests in the final resonator geometry. With the increased mode separation achieved, a simple loop-bending procedure allows the

Table II. Performance of the low-β resonator.

Frequency:	151.10 MHz (at 300 K)
	151.69 MHz (at 4.2 K)
Mode Separation:	∿5.2 MHz
Accelerating Gradient:	3.0 MV/m (routine)
	3.8 MV/m (maximum to date)
Unloaded Q:	$\sim 2\times10^{7}$
Energy Content:	$15\ \mathrm{mJ/(MV/m)^2}$
Radiation Pressure Frequency Shift:	$40\ \mathrm{Hz/(MV/m)^2}$
Vibration-Induced Frequency Modulation:	∿50 Hz (fwhm)
Net Heat Dissipation:	$0.7\ \mathrm{W/(MV/m)^2}$ ("standard")
	$1.5\ \mathrm{W/(MV/m)^2}$ (worst observed)
Field Emission Threshold:	∿2.5 MV/m

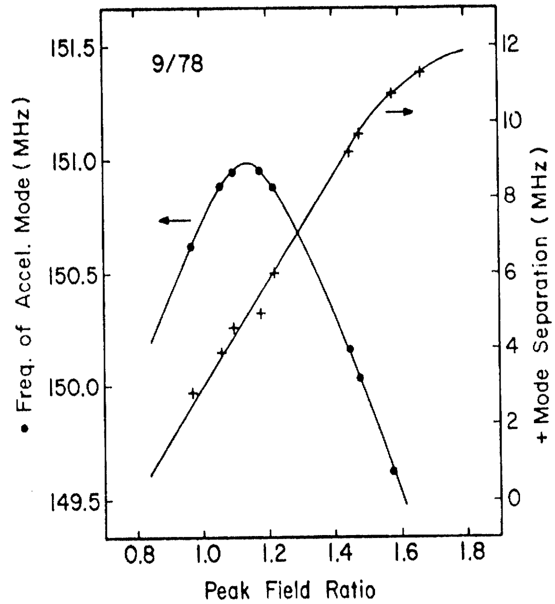

Figure 2. RF Modes in the modified low-β resonator.

electric fields in the two side gaps to be made equal to 1% or better.

The principle of phase stabilization by direct RF feedback has been described in detail elsewhere.[6,7] The variable-coupling system mentioned above is also important for stabilization, in order to achieve the optimum resonator loaded Q. Using 175 W of RF power, the low-β resonator can be stabilized at 3.0 MV/m with a jitter of about ±0.1° and ±0.1% in phase and amplitude, respectively.

IV. Prototype low-β Module

Figure 3 shows the checkout and re-assembly at Stony Brook of the prototype low-β module following initial tests and resonator modifications at Caltech. The 40-liter capacity helium tank is visible above the resonators (supported by a temporary clamp), but the thermal-transition stack-ups are not yet in place. Figure 4 shows one end of the module in more detail, including the

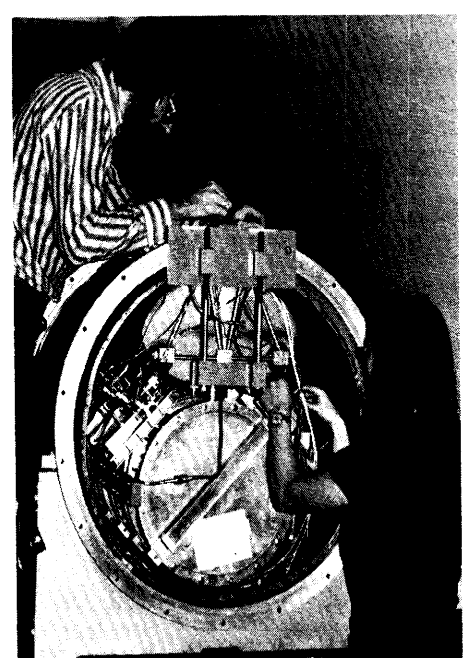

Figure 3. Re-assembly of the prototype module.

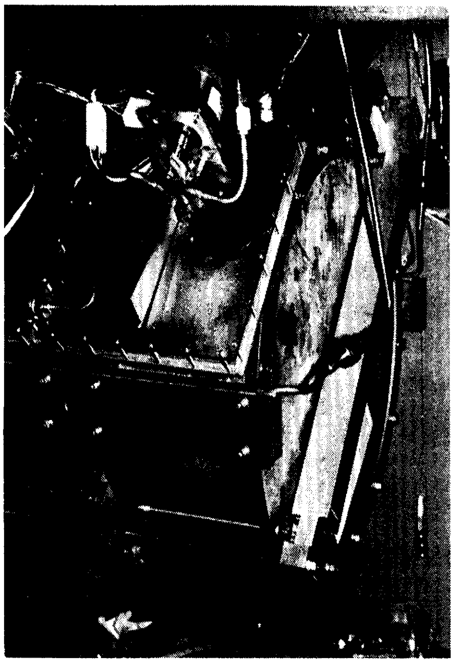

Figure 4. Detail view of the prototype module, showing the variable-coupling resonator and squeezing bars.

77 K variable-coupling resonator and the resonator squeezing bars. Module cooldown to 4.2 K requires about 24 hours, with a complete warmup taking somewhat longer. The system has been exposed to several severe vacuum failures while cold with no permanent ill effects. An efficient pre-cool system allows the ∿150 kg resonator assembly to be brought from 77 K to 4.2 K with the consumption of only ∿50 liters of liquid helium. Standing losses at 4.2 K are about 4 W.

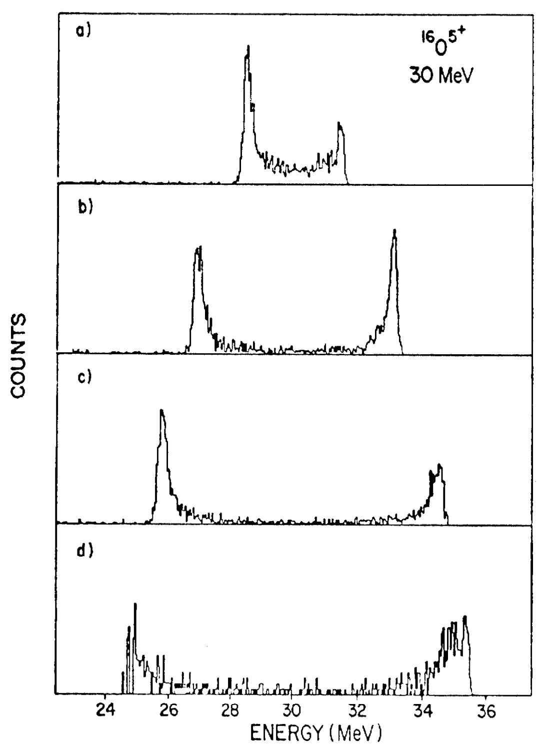

Figure 5. Energy spectra of an $^{16}O^{5+}$ beam after the module, with 1-4 phase-locked resonators in operation (a) through d), respectively).

V. Beam Tests with the Module.

The prototype accelerator module was mounted on a beam-line at Stony Brook and tested by injecting a 30 MeV ^{16}O beam in the 5^+ charge state from the FN tandem. Figure 5, parts a)-d), show the energy spectra of the beam after being accelerated and decelerated by (1)-(4) resonators, respectively. The resonators, operating at ∿2.3 MV/m accelerating gradient, were phase and amplitude stabilized to an external frequency synthesizer, with the relative phase of each resonator (except the first) adjusted to produce maximum energy gain. The shapes of these energy spectra result from the random arrival phase of the beam with respect to the frequency synthesizer and from strong (de)focussing effects for arrival phases which correspond to bunching or debunching.

VI. Present Status and Timetable.

The Caltech-Stony Brook LINAC collaboration is now in a "transfer-of-technology" phase which will result in the preparation of conditions or facilities for mass-producing accelerator modules. Fabrication of the first production-model cryostat is well underway, a second set of 4 low-β resonators is being produced by the Caltech Central Machine Shop, and a lead-plating facility is being set up at Stony Brook. It is expected that the first production-model low-β module will be under test by June of this year. At the same time, development work proceeds at Caltech on the prototype high-β resonator. First bead-tests of a room-temperature model have been completed, and 4.2 K tests should also be in progress by June. Orders have been placed for a 400 W refrigerator to cool the LINAC and for various items connected with the upgrading of the Stony Brook tandem. It is anticipated that a full LINAC construction schedule can begin in mid-1979 and be concluded in about two and one-half years.

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