FURTHER DEVELOPMENT OF THE STONY BROOK SUPERCONDUCTING HEAVY-ION LINAC*

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Summary

We describe several projects now underway, or recently completed, to extend the performance of the the Stony Brook tandem/linac accelerator. The present 16 low-β resonators in the linac will be replaced with new quarter-wave type (QWR) resonators over the next 18 months. Development has progressed from an aluminum room-temperature model to a lead-copper prototype, which is now undergoing superconducting tests. The upgrade will extend the useful mass range of the linac from the present A=74 (germanium) to A=127 (iodine). Other developments include: a computer program which calculates resonator phases from a linear model, a deflector which permits a reduction in the duty factor of the beam, and modifications to the helium cryogenic system.

Introduction

The Stony Brook tandem/linac accelerator system has been providing heavy-ion beams for nuclear physics research since its dedication in the spring of 1983. The linac employs 40 lead-plated copper cavities to achieve final energies from 10 MeV/A for ^{16}O to 4.5 MeV/A for ^{74}Ge. Detailed description of the system as of 1985 may be found in several recent status reports and references therein.[1][2] The present paper reviews the status and performance of improvements to the system.

Quarter Wave Resonators

It has been known for some time that the linac performance could be greatly enhanced by replacing the low-β split-loop resonators with new resonators of quarter-wave geometry (QWR). The main difficulty with the split-loops is their very thin loop arms, which make them sensitive to mechanical vibration. In addition, these resonators (unlike the high-beta resonators in the linac) have a lossy joint where the loop is joined to the can. The QWR is extremely stiff and have its only normal joint in a region of very low current.[3] In addition, the 2-gap geometry of the QWR offers an improved velocity acceptance. For this reason, the new resonator was designed with a somewhat higher β-optimum (0.068) than that of the split loop (β=0.055). The energy gain per cavity is expected to be 510 keV/q with a dissipation of 6 watts.

In designing the new QWR, electric fields along the beam axis were calculated with the program POISSON and compared with bead-test measurements on an full-size aluminum model. As shown in Fig. 1, the two are in good agreement. From this data, the transit time factor and stored energy were calculated, as summarized in Table 1. In addition, POISSON was used to establish the desired shape of the doughnut on the center conductor by calculating the electric field along its surface. The final dimension for the length of the center conductor was determined by experiment and was found to be within a centimeter of the value calculated.

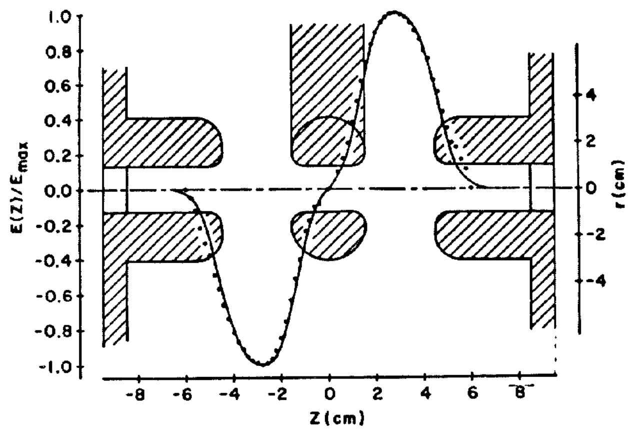

Fig. 1. Measured (dots) vs. calculated (solid line) axial E-fields in the prototype QWR.

In the construction of the first copper prototype QWR, the inner conductor the shorting plate and a small portion of the outer conductor are machined from a single OFHC copper forging, similar to the technique described by Steck et al.[4] The outer and inner conductors were electron beam welded together and the step at the joint was machined, leaving a smooth inner surface. There were some difficulties in brazing the drift tubes into the wall of the outer conductor, so that some small defects in the braze were smoothed over with soft solder. The resonator was then plated with 1μm of Sn/Pb alloy (7/93). No porosity has been observed in either the welded or the brazed joint.

We have not yet obtained a satisfactory low temperature test of the prototype QWR. The first test was plagued by an excessive amount of multipacting and a Q of only $6*10^7$, even at low fields. After warming up the resonator, it was found that the surfaces of the acceleration gaps had become badly discolored indicating some vacuum related problem (a new epoxy used on the cryostat heater is one suspect). The resonator has been replated and is undergoing a second test.

RF Coupler

RF power is coupled into the QWR by a small loop which passes through a hole in the shorting plate. The coupler is anchored at 80K and is thermally isolated from the 4K resonator by a G10 guide and a teflon spacer. The assembly is isolated from room temperature by a rigid coax which is constructed of thin-wall stainless tubing and plated on the conducting surfaces with a 15 μm layer of copper. Attenuation in this section was measured to be less than 1dB/100ft. The coupler has a large physical range, which has allowed us to reach critical coupling at both 4K and 80K.

Table 1. QWR Parameters

Frequency	150.408 MHz
β_{opt}	0.068
Stem length	50.5 cm
Inside diameter	17.0 cm
Accel. gap length	3.0 cm
Energy content	39 $mJ/(MV/m)^2$

Future Linac Performance

The performance of the upgraded linac was estimated by assuming a gradient of 3 MV/m for the new QWRs and 2.5 MV/m for the existing high-β split-loops. The improvement for heavy beams is especially impressive. Charge state combinations for various heavy beams were measured with the tandem injector operating at 9 MV with foil stripping. For an iodine beam (A=127) charge state 13+ in the tandem is practical, and the resulting 126 MeV beam can be further stripped to 27+ before entering the linac. This gives a final linac energy of 600 MeV (4.7 MeV/A). The final intensity is limited by the low stripping efficiency and tandem foil lifetime to about 0.5 pnA.

Deflector

The pre-linac bunching system operates on the 16th subharmonic of the 150 MHz linac frequency to provide an output pulse every 106 ns.[5] The new beam deflector[6] provides a capability (which is essential for some experiments) to extend this repetition time by "down-counting" to a multiple of 106 ns. In operation, the deflector normally deflects the beam away from a pair of slits with a 1.0-1.5 kV potential across its plates. When the deflector is triggered, the plate voltage is brought to zero and a beam pulse is allowed to pass through.

The high-voltage on the deflector "hot-plate" is switched by two EIMAC 8940 triodes operating in parallel. The MOSfet grid driver circuit converts a standard TTL pulse into the +20V and -12V biases required to turn the tubes on and off. With the tubes in the "on" state, the voltage drop across the plate resistor effectively grounds the hot-plate. The plate resistor is constructed of seven forced-air-cooled ceramic resistors in parallel with a total resistance of 560 ohms.

The deflector has been used with duty factors as high as 50%, producing a pulse every 211 ns. Dissipation at this high duty factor limits the maximum deflecting voltage to 1.2 kV, yielding a beam suppression ratio of 10^3. At lower duty factors, the deflector voltage can be increased to 1.5 kV or so, and suppression ratios of 10^4 or better are easily achieved (fig. 2).

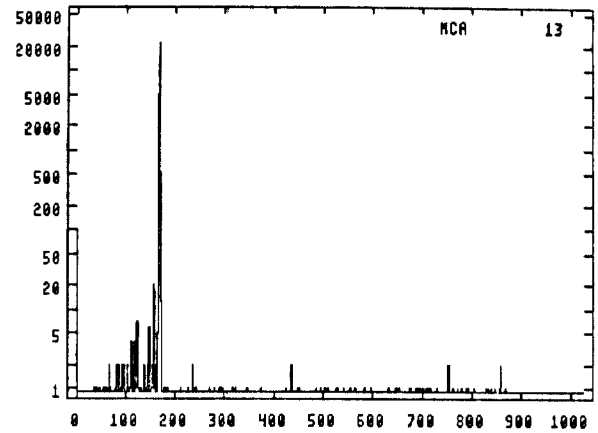

Fig. 2. Time spectrum (1 ns/ch) with deflector operating at 1.5 kV and 1:8 duty factor.

Table 2. Deflector Parameters

plate gap	2 cm
length	50 cm
voltage	1-1.5 kV
risetime	<50 ns
capacitance	36 pf

Tin/Lead

A vacuum accident in linac module 8 resulted in some deterioration of the performance of its resonators. This cryostat was later removed and its resonators replated with Sn/Pb (7/93). The tin/lead surface has the advantage that the plating operation is simpler than that for pure lead because of the higher throwing power of the Sn/Pb bath. The plated surface also has greater chemical stability, so that it can be simply rinsed with deionized water and dried with nitrogen after plating. Module 8 was put back on line and the resonators helium conditioned in October 1986.

Figure 3 compares the performance of resonator 8.3 with the original Pb surface and the new Sn/Pb surface. The original surface had been prepared by plating 10 μm Pb onto the copper resonator followed by a chemical polish. (This was the technique used in plating all of the linac modules.) The new tin/lead surface was plated 1 μm thick with no chemical polish. The Q-data in fig. 3 imply that Sn/Pb is certainly no worse than lead at typical linac operating fields. The significantly higher low field Q of 1 μm Sn/Pb greatly increases the efficiency of our re/debuncher (also replated), which typically runs below 1 MV/m.

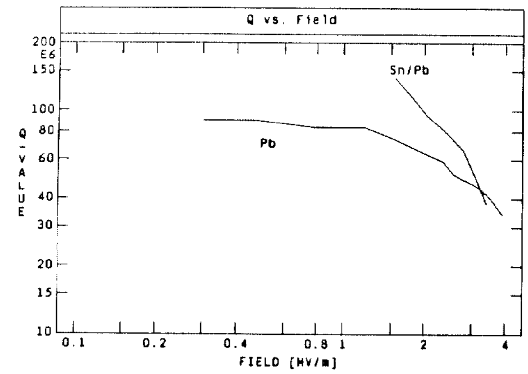

Fig. 3. Resonator Q vs. accelerating field for lead and tin/lead surfaces in linac resonator 8.3.

Cryogenic Improvements

The performance of the linac helium refrigerator has been enhanced by adding a wet engine expander of the Koch-Fermilab type and by replacing the commercial helium U-tubes at the 13 cryostats with those designed and constructed locally.[1] An automatic load-balancing device was also incorporated. As a result of these improvements, 225 watts of cooling are now actually available for cooling resonator rf dissipation, compared to 125 watts previously.

In the next year the 15 meter long helium line which feeds the rebuncher cryostat in the target room will be rebuilt in a similar way. The line will be used to charge a 1000-liter buffer cryostat in the target room approximately once a week. As now, the He gas return will be through a warm line directly to compressor suction.

Longitudinal phase space

Considerable effort has been made in the last year to achieve very narrow and time-stable beam bursts on target. The longitudinal (E-t) phase space is reoriented with a re/debuncher resonator in the target area, 15 meters from the Linac and 9 meters from the large target chamber on the 15 degree beam line. For the 125 MeV sulfur beams presently of interest, a stable bunch width 200 psec FWHM is now routinely achievable. The beam width at the rebuncher can be made sufficiently narrow ($\simeq$ 0.8 ns FWHM) to give a very clean profile to the final bunch (see fig. 4).

For good linac time performance (which corresponds to very low energy spread $\Delta E/E = 1/2000$) the operator must minimize any phase space degradation by very careful phasing and resonator-controller operation. Setup problems can be detected during the phasing by monitoring the bunch width (and hence the linac energy spread) near the rebuncher location. Any "tails" observed in the time structure must be removed before phasing proceeds. An improved diagnostic device is under development which will measure the complete 2-d longitudinal phase space.

Improved Linac Set-Up Procedure

The computer control system for the linac is continually being updated and improved, largely to increase the ease of operation. For example, a program has been written which calculates the proper acceleration phase of the current resonator during the linac set-up. The operator can either elect to use this calculated value or allow the computer to find the correct phase empirically by measuring the energy gain vs. phase curve. This "auto-phasing" program reduces the linac set-up time to only 1-2 hours, much of which is devoted to tuning the 13 quadrupoles to optimize beam transmission.

The model for the program is the following.[7] If a resonator is at the correct accelerating phase, the phase for the next resonator can be found from the phase difference given by the approximation:

$$-\Delta\phi = \{ \Delta d(\omega/v) + \Delta\theta \}\mathrm{mod}360$$

where:

Δd is the distance between the resonators
ω is the resonator freq. (deg/sec)
v is the ion velocity
$\Delta\theta$ is a phase offset due to cable lengths

Data from 37 linac runs were used to find the unknowns Δd and $\Delta\theta$ by a least-squares fit.

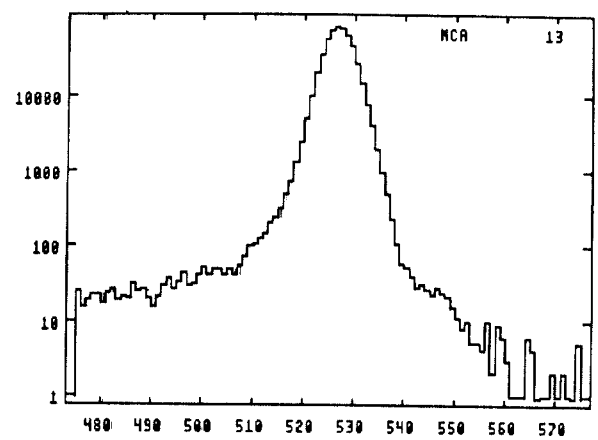

Fig. 4. Time spectrum of a rebunched linac beam in the target chamber (37 psec/channel).

References

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