STATUS OF THE ARGONNE SUPERCONDUCTING-LINAC HEAVY-ION BOOSTER

J. Aron, R. Benaroya, L. M. Bollinger, B. E. Clifft, K. W. Johnson,
P. Markovich, J. M. Nixon, R. Pardo, K. W. Shepard, and G. Zinkann

Argonne National Laboratory, Argonne, Illinois 60493

Summary

The Argonne Superconducting-Linac Heavy-Ion Booster is nearly complete. The linac now contains 22 of the complement of 24 resonators which will eventually be installed. During the construction period, the completed portion of the linac has provided useful beams for nuclear and atomic physics experimental programs. The linac-control system has been developed so that much of the more complex control functions are performed automatically.

Introduction

The Superconducting-Linac Heavy-Ion Booster has been developed as a prototype of ATLAS, the Argonne Tandem-Linac Accelerator System.[1] When complete, ATLAS will accelerate heavy-ion beams to energies over 25 MeV/A.

The superconducting linac booster[2,3,4] consists of four cryostats, which will contain a total of 24 independently phased split-ring superconducting resonators.[5] The first 11 of these resonators will have a matched velocity of 0.062c and the last 13 will have a matched velocity of 0.105c. At present the linac contains the full complement of high-beta (0.105c) resonators but only eight low-beta (.065c) resonators are installed. In this configuration, the linac now provides a total accelerating potential of 18 MV.

Heavy-ion beams are injected into the linac from an upgraded FN-tandem Van de Graaff accelerator. Typically, the tandem operates at an effective terminal voltage of 8.5 MV. The negative ions needed for injection into the linac are provided by an inverted sputter source.

In order to maintain the good beam quality from the tandem, it is necessary to bunch the beam into pulses approximately 100 ps wide at the entrance to the linac. This is accomplished with a two-stage bunching system. First, a room-temperature gridded buncher[6] using a sawtooth-like waveform bunches 70% of the D.C. beam into pulses approximately 1 ns wide (FWHM). These pulses are further bunched to a width of 100 ps at the linac entrance, using a superconducting low-beta resonator.

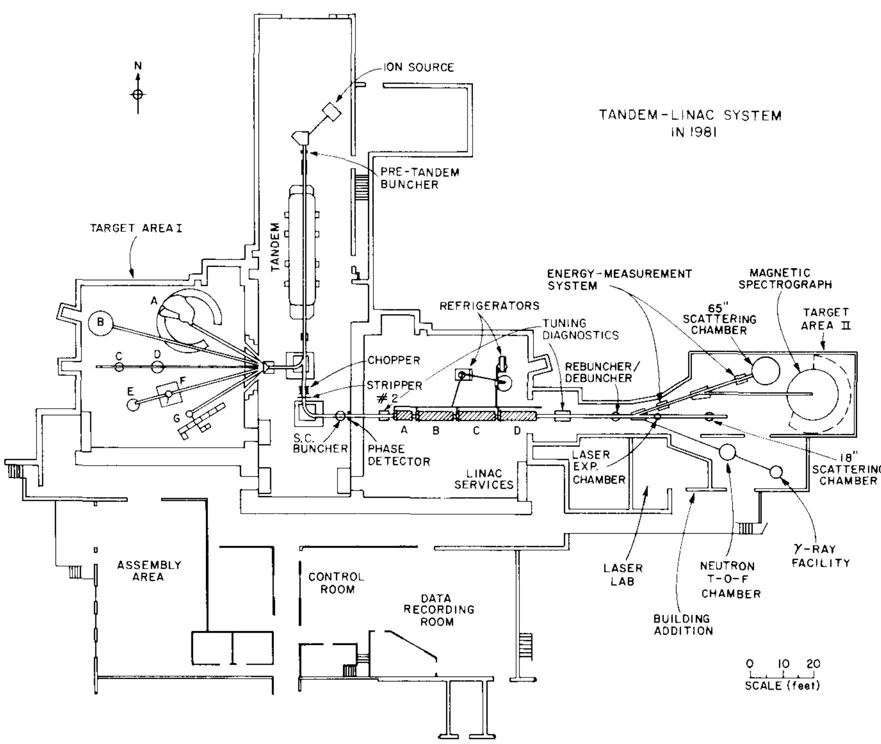

Fig. 1. Overall layout of the accelerator system

This paper discusses the status of the project and the operating experience during the last two-and-a-half years. An associated paper in these proceedings discusses beam optimization on the linac and measurements of the linac beam quality.

Project Status

Construction

The fourth (and last) cryostat of the booster project was placed on-line in June 1981. At that time, four resonators out of an eventual complement of eight were installed. This brought the linac resonator total to 20, 13 high-beta and seven low-beta resonators. Due to improper assembly of the VCX fast-tuning system, two resonators in the new cryostat could not be operated. After providing beam for the experimental program through July and August, cryostat B was removed for repair and for installation of two additional low-beta resonators.

The B cryostat was placed on-line again on September 30. At this time, the cryostat contained six resonators. Subsequently, it was determined that the field pick-up line to one resonator was inoperative. The linac began providing experimental groups with heavy-ion beams again on October 14 with a total of 21 resonators operating: eight low-beta and 13 high-beta. The present physical layout of the facility is shown in Fig. 1.

The physical growth of the linac over the past two years caused the capacity of the original 100-watt helium refrigerator to be inadequate. This problem was solved in late 1980 with the installation of a 300-watt CTI-2800 helium refrigerator. This refrigerator has operated reliably since installation. Only two or three minor system problems have developed over this period.

One of the most important design decision for the heavy-ion linac was the use of independently phased resonators. This feature is essential for the efficient acceleration of a large range of heavy-ion species. Another important benefit of independent phasing is that the linac operation is largely configuration independent and it has been conceived from the beginning that repairs to components in one cryostat of the linac could be made while the remainder of the linac continued to provide useful beams for the experimental program.

This modular feature was fully exploited in the repair, expansion, and servicing of B cryostat in September. The cryostat was replaced in the linac by a beam pipe containing only a vacuum pump, beam scanner, and small steering magnet, and the experimental program was resumed. This meant that the beam pulses had to drift a distance of 4 meters before longitudinal refocusing could occur in the next resonator. We found this presented no practical problem in terms of beam quality. Ray-tracing calculations suggest that some distortion in the longitudinal phase ellipse occurred, but this is not a significant problem for experiments currently operating. In fact, timing resolution of 117 ps was obtained in an experiment using 229 MeV ^{28}Si during this period.

Control System

The linac-control system is based on a PDP 11/34 minicomputer with 128K words of memory and a floating-point processor. Two fast disk drives provide a total of ten megabytes of storage space. The basic control system resides on one 2.5 megabyte disk, which allows the second disk drive to serve as a system backup. Permanent file storage is by floppy disks. An LSI 11/2 μ-processor is used for thermometry I/O operations.

The control-system software operates under the multi-tasking, multi-user system RSX-11M. The multi-tasking allows many different functions to go on simultaneously, including those not directly related to system operation. The computer provides the major functions of linac control, linac monitoring, complex calculations, and system development.

During the past two years, the linac-control system has evolved from a rudimentary system providing essentially manual control of the linac into a system that is largely automatic in many aspects. For example, the linac tuning is completely automated, normally requiring operator assistance only to correct beam steering as the tune-up proceeds. Also, a change of the linac energy is now accomplished by a simple request from the user at the control console. Features of this type are essential because of the wide variety of beams accelerated and because the linac functions largely as a user-operated facility.

The linac-control hardware is interfaced to the computer system through a bit-parallel, byte-serial CAMAC highway. Control of the linac is executed by the setting of reference voltages. The system is monitored using multichannel ADC's for low-resolution data, such as thermocouples, and input registers for information requiring higher resolution. The basic system functions with only four types of commercially available interface modules, making it possible to stock replacement modules to be used in the event of a failure. In practice, CAMAC reliability has been excellent. In the past 2½ years, only two module failures have occurred, and the overall highway has performed flawlessly.

The operator interfaces to the system through a control console (shown in Fig. 2) consisting of the following items:

1) a 16-key touch panel,
2) two computer-assignable knobs for control,
3) a color TV,
4) hard-copy system console,
5) storage-scope terminal,
6) line printer/plotter, and
7) B-W monitors for thermometry information.

The I/O for the console is through RS232 ports and a parallel CAMAC crate. Almost all functions normally needed for control of the linac are accessed through the touch panel. Manual control of an element can be requested and assigned to the knob assembly below the touch panel. In addition to the analog-like control of an element, a specific value can be requested for a parameter through a numerical key pad to the right of the touch panel.

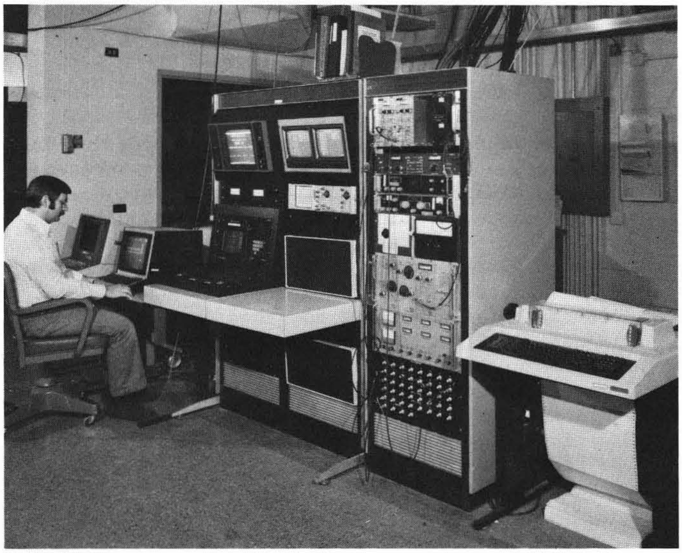

Fig. 2. View of Linac control console

The organization of the computer-control software system is shown in Fig. 3. The linac software is driven from a data-base table which contains all parameters of the linac and bunching system. The data base includes "temporary" parameters relevant to the current beam being accelerated (such as resonator phase angles, accelerating-field levels, and the beam-energy profiles along the linac) and also "permanent" parameters such as resonator type, distances between linac elements, and field calibrations.

The table-driven feature of the computer-control system results in a highly flexible system. Linac components can be effectively removed from the system, or the system I/O can be reconfigured to bypass a malfunctioning module by simple modification of the data base in the table.

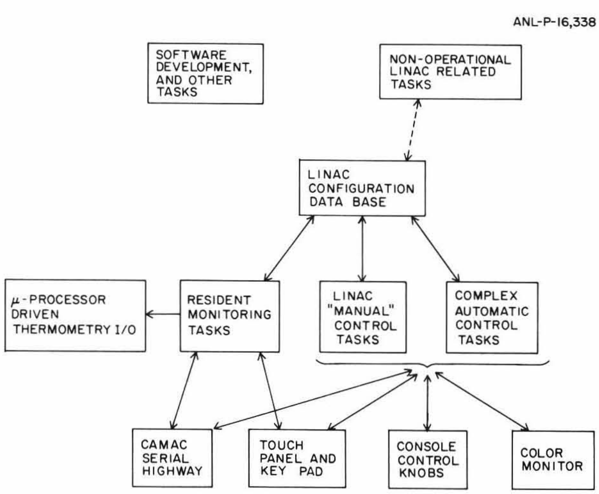

Fig. 3. Structure of the linac-control software

Operating Experience

As the construction of the linac has proceeded, the existing portion of the linac has provided useful beams to experimental groups. From March, 1979 through September, 1981 the linac has provided over 7200 hours of scheduled beam time accelerating some 18 species ranging from ^{4}He to ^{65}Cu. In the last three years, the linac has evolved from a mostly developmental project into an operating accelerator. The percentage of total possible time devoted to providing beams for the research program has increased from 25% in 1979 to over 63% in 1981.

The research program undertaken at the linac has taken advantage of the high degree of flexibility of the tandem-linac system. The percentage of the total running time for various isotopic beams accelerated during the past is shown in Fig. 4. The trend towards higher-mass ions is reflective of the installation of low-beta resonators in late 1980, which opened the mass region above sulphur to serious exploration.

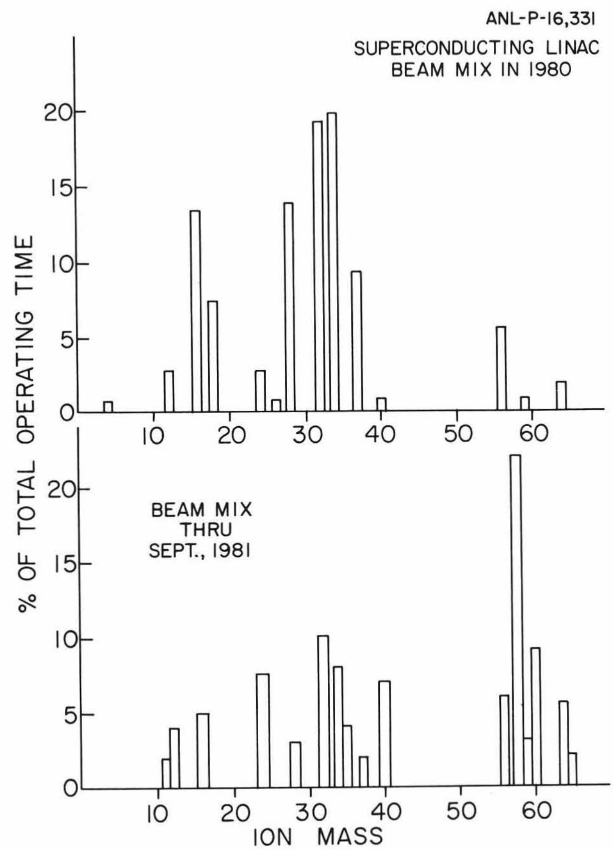

Fig. 4. Beam mix accelerated by Linac for the experimental program in 1980-Sept. 1981

In the three years of linac operation, a significant pool of data has been collected on resonator on-line performance. The resonators have shown a high degree of reliability and an impressive ability to tolerate significant accidents. In one case, a refrigerator failure caused the entire linac to warm to approximately 40°K before the problem was corrected. Upon cooling, only two resonators needed reconditioning, and that was accomplished in approximately four hours.

At present, the average on-line operating field level is 3.5 MV/m for the low-beta resonators and 2.7 MV/m for the high-beta resonators. In off-line tests, the average field obtained is 4.2 MV/m for the low-beta resonators and 3.7 MV/m for the high-beta resonators. The different performance of the resonators appears to stem from three nearly independent causes of comparable magnitude. These causes are: 1) a deterioration of the average high-beta resonator performance due to catastrophic vacuum accidents and other abuse over the past three years; 2) a difference between the average on-line and average off-line performance of high-beta and low-beta resonators, and 3) an intrinsic difference in the average performance of high-beta versus low-beta resonators. One factor which contributes to points two and three is that resonators can be conditioned more effectively off-line than on-line, and low-beta resonators can be more effectively conditioned than high-beta resonators.[7]

A systematic program is underway to understand, in detail, the causes for the field-level performance differences between on-line and off-line operation. The resonators which have experienced field degradation due to accidents will be removed and reprocessed as time permits. It has been our experience that reprocessing resonators restores their original field performance.

It has been our experience that when the resonators are operated with fields up to 90% of their maximum levels, the linac operates in an almost trouble-free manner. Specifically, the need to condition resonators is essentially eliminated for periods of weeks. In addition, the fraction of time in which one finds all resonators properly phased locked and the amplitude stabilized (known as "in-lock fraction") approaches 100%. When the experimental requirements demand operation at the maximum achievable energy, experience indicates 2% of all resonators require reconditioning each day. The in-lock fraction in this case will average approximately 90%.

Operational Problems

A persistent problem in the resonator operation has been in the slow-tuner control. The slow tuner is a pneumatic device consisting of a bellows assembly mounted to one end plate of each resonator. By pressuring the bellows with helium gas, the end plate is elastically deformed and the eigenfrequency of the resonator is modified. In the original design, the pressure in the bellows was controlled by automatically introducing or exhausting helium by means of fast-acting solenoid valves. These valves have proven to have a limited lifetime in this application.

In the last six months, a new slow-tuner control system has been implemented on 70% of the resonators. The system operates on a fixed quantity of gas in the slow-tuner system. By electrically heating a reservoir common with the bellows and thermally grounded to the liquid-helium system, the bellows pressure is varied as required. This system is still being refined, but the initial results indicate that this technique should be a significant improvement over the old control method.

Future Plans

The accelerator development is proceeding in anticipation of expansion of the present booster into the ATLAS accelerator. The ATLAS project will provide three additional cryostats containing a total of 18 resonators, resulting in a linac with a total of 42 resonators in seven cryostats. A new split-ring resonator with a matched velocity of 0.16c is being developed for this phase of the project. The new design uses the same housing as the present high-beta resonators, but a redesigned drift tube and ring assembly will be employed. The operating frequency will be at 148.5 MHz, which is 3/2 times the frequency of the present resonators. The fabrication of the prototype resonator is nearing completion.

The present mass limitation on ions which can be accelerated with the linac is set by the 90° analyzing magnet of the tandem. This magnet is over 20 years old and was originally installed for an EN tandem Van de Graaff. An ischronous superconducting-magnet system consisting of two 45° bending superconducting dipole magnets is planned to replace the current analyzing magnet. A third superconducting dipole will be used between the two linac sections in the ATLAS system. The prototype of these magnets has been designed and is in the construction phase.

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