STATUS OF THE ARGONNE SUPERCONDUCTING-LINAC HEAVY-ION BOOSTER*

J. Aron, B. Benaroya, L. M. Bollinger, B. G. Clifft, W. Henning,
K. W. Johnson, J. M. Nixon, P. Markovich and K. W. Shepard
Argonne National Laboratory
Argonne, Illinois 60439

Summary

A superconducting linac is being constructed to provide an energy booster for heavy ions from an FN tandem. By late 1980, the linac will consist of 24 independently-phased superconducting resonators, and will provide an effective accelerating potential of more than 25 MV. While the linac is under construction, completed sections are being used to provide useful beam for nuclear physics experiments. In the most recent run with beam (June 1979), an eight-resonator array provided an effective accelerating potential of 9.3 MV. Operation of a 12-resonator array is scheduled to begin in October 1979.

Introduction

This paper reports the status of the Argonne superconducting heavy-ion linac, which has been developed to boost the energy of heavy-ion beams from an FN tandem accelerator.[1,2,3] The intent of the project has been both to develop superconducting rf technology for the acceleration of heavy ions, and to provide a useful accelerator for use with the Argonne FN tandem. At this time all significant development tasks have been completed. Current funding provides for a linac of four modular sections, of which two have been completed.

The physical layout of the accelerator system is shown in Fig. 1. The pre-tandem beam-bunching system and a post-tandem superconducting buncher are housed in the tandem vault. The linac and most of the helium refrigeration system are located in a previously existing target room, with the linac output going into a small new target area.

Preserving the good quality of the tandem beam requires an exceedingly narrow beam pulse injecting the linac. This has been accomplished with little loss in the tandem beam intensity by a two-stage bunching system.[4] The pre-tandem buncher is a gridded-gap (room temperature) driven by a sawtooth-like voltage generated by

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*Work performed under the auspices of the Office of Basic Energy Sciences of the U. S. Department of Energy.

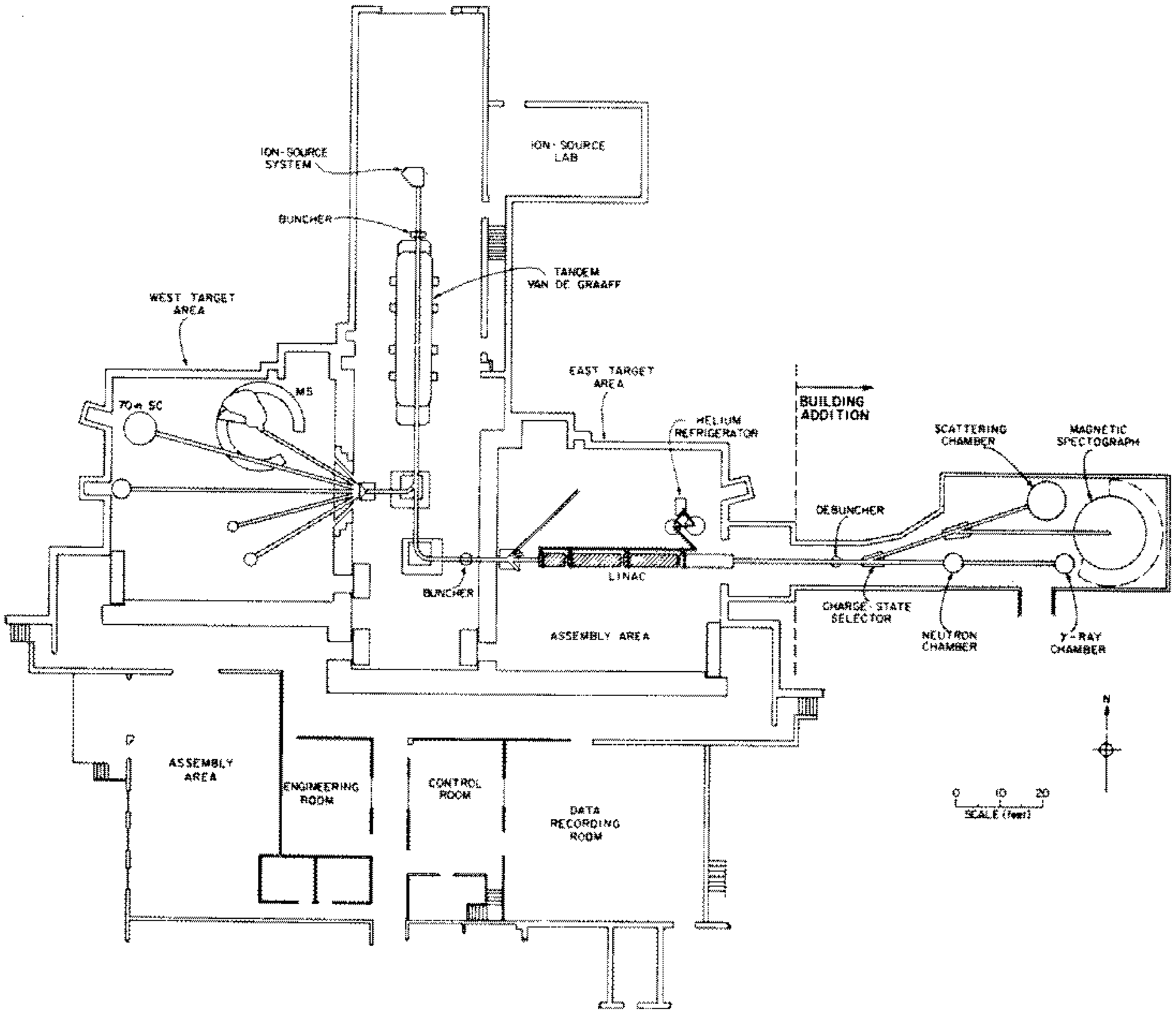

Fig. 1. Overall layout of the accelerator system.

superposing four rf harmonic components. This system compresses about 80% of the dc tandem beam into 1 nsec pulses at the tandem output. The post-tandem buncher is a single superconducting split-ring resonator which linearly compresses these pulses to a width of less than 100 psec at the linac entrance.

The linac is formed of modular cryostat sections any one of which can be taken off-line without disturbing operation of adjacent sections.[1] Figure 2 shows a cross section of a typical cryostat. Thus the linac consists of an independently-phased array of superconducting split-ring resonators, each of which can provide more than 1 MV of effective accelerating potential over a range of a factor of two in particle velocity.[5,6,7] Independent phasing allows the velocity profile of the linac to be varied over a wide range, and provides a high degree of operational flexibility. Focusing within the linac is accomplished with a superconducting solenoid following every pair of resonators.[8] Beam diameter within the linac is typically kept smaller than 6 mm both to prevent beam impinging on the superconducting surfaces of the resonators and to limit radial variation of the energy gain within the resonators.

The linac target area was constructed in 1977, and installation of the experimental equipment shown in Fig. 1 will be completed in 1979-80. For initial operation, experiments are being performed on the zero-degree beam line. Later, with the installation of the superconducting debuncher-rebuncher and the charge selector magnet, the location of the various experimental stations will be changed to that shown in Fig. 1.

The modular nature and variable velocity profile of the linac have permitted useful operation with completed sections while construction continues. Beam acceleration tests began in June 1978, with two resonators in a six-foot cryostat module, and have continued to the present array of twelve resonators in two twelve-foot cryostats, scheduled to run with beam in October of this year.

Table I outlines the several runs with beam. Initial operation revealed a number of system flaws, and the first three runs were focused primarily on system development, as has been discussed elsewhere.[3] As is discussed below, in the last two runs with beam the remaining significant development tasks have been completed, and the emphasis has shifted to providing beam for users.

<u>Linac Systems</u>

The fourth run, in March 1979, was the first in which beam was provided for users over an extended period of time. However three significant problems remained with linac performance. Firstly, the resonators provided on-line an effective accelerating potential of 0.9 MV/resonator, substantially less than the 1.4 MV/resonator obtained in off-line tests. Secondly, mechanical vibration of the resonators caused occasional excursions of rf eigenfrequency beyond the range of the fast tuning system. The consequent loss

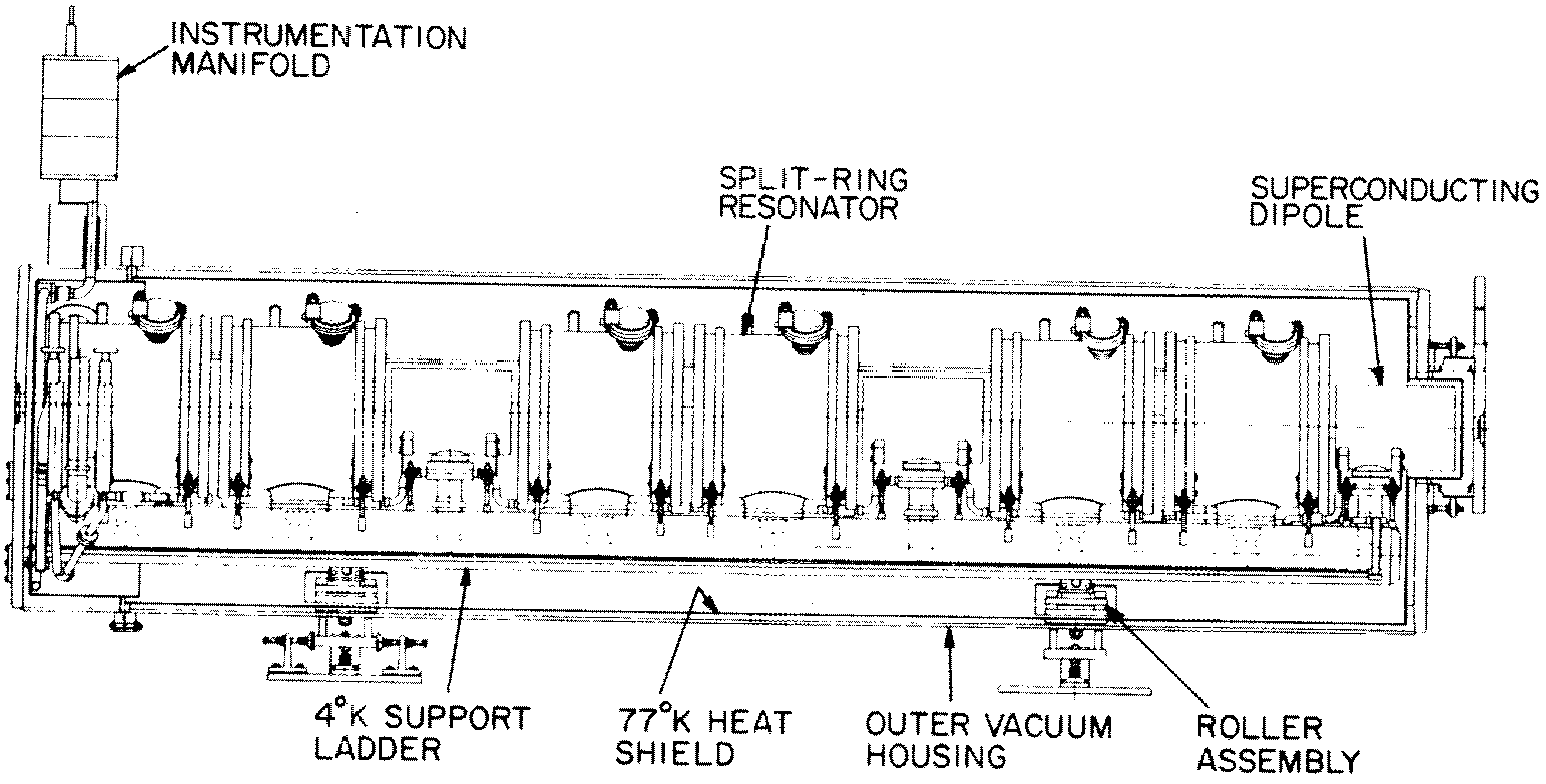

Fig. 2. Cross-section of a linac cryostat module. The cryostat disassembles by rolling the resonator array, together with all cryostat plumbing and electrical leads, out of the vacuum housing.

TABLE I

Outline of Linac Beam Tests

Date	Duration	Number of Resonators	Max. Acc. Potential	Ion Species
June 1978	3 days	2	1.6 MV	O_{16}^{6+}, F_{19}^{6+}
Sept. 1978	5 days	5	4.0 MV	O_{16}^{6+}
Dec. 1978	8 days	6	5.2 MV	S_{32}^{14+}
March 1979	31 days	8	7.6 MV	S_{32}^{14+}
June 1979	30 days	8	9.3 MV	$S_{32}^{14+}, Si_{28}^{12+}, O_{16}^{8+}$

of phase control caused output energy variations which required blanking of either the beam or data taking for 10-20% of the time, i.e., the effective duty factor of the linac was 0.8 - 0.9. Thirdly, the linac output energy was found to vary by a few parts in 10^3 over a time period of several hours.

The resonator field level was limited by thermal instability at an rf input power less than the design level of 4 watts. Following the fourth run, it was found by radiography that plastic tubes used to vent helium gas from the resonator interior were out of position in a way that would cause a gas bubble to accumulate and prevent cooling of a critical portion of each resonator. The tubing was modified with the result that in the fifth run with beam, the effective accelerating potential was increased to 1.2 MV/resonator.

The rf control system was modified to provide rf damping of mechanical vibration in each resonator. This was achieved at the cost of varying the rf amplitude in each resonator at the frequency of the mechanical motion. In the system used, an amplitude variation of 2 parts in 10^4, which has a negligable effect on beam quality, reduced the vibration by 40%. The system also provides temporarily increased damping for any resonator that loses phase-lock. In this condition, the output beam is useless, so that an increased rf amplitude variation is tolerable. The result is that vibration resulting from any large mechanical perturbation is quickly damped out. In the fifth run with beam, the rf damping system reduced the vibration-induced loss of phase control to less than 1% of the time for the eight-resonator array.

Finally, it was found that the slow drift in linac output energy was correlated with a change in the liquid nitrogen level in a portion of the cryostats through which the rf cabling is run to the resonators. Apparently, the liquid nitrogen permeates the rf cabling and causes a slight change in electrical length. Thus variations in the liquid nitrogen level induce a slight shift in the resonator rf phase and amplitude, and in the beam energy gain. Modification of the control system to maintain a constant liquid level eliminated the drift in output energy.

Linac Operation

More than 1800 hours of beam time have been logged. The most outstanding operating feature has been the general reliability of the linac.[3,9] While accelerating beam, the linac systems generally require little or no operator intervention for periods of many hours. Linac downtime has been small, typically an hour per day.

Beam quality is essentially as expected,[1] although three factors limit presently available performance. (1)-The second stripper is temporarily located upstream of the tandem beam-analyzing magnet, rather than at the time focus at the linac entrance; thus energy straggling in the stripper dominates the output time-energy spread. (2)-In the temporary linac configuration used thus far, a six-foot gap exists between two cryostat modules which produces a significant time spread of the particle bunch prior to acceleration through the final cryostat module. (3)-Also, absence of a debuncher-rebuncher downstream of the linac prevents obtaining the full time or energy resolution capability of the linac in the experimental areas.

Linac tuning has proven straightforward. At present this is accomplished by calibrating the rf phase of each resonator by varying the phase and observing the output beam energy. In this procedure, the first resonator is tuned, with all others off, and then one successively turns on and tunes each resonator in the chain. At present tuning is done manually, and requires several hours. Eventually, the operation will be fully computer-controlled, and should go very much more rapidly.

Future Plans

Planned hardware additions in 1980 include modifying a six-foot cryostat and constructing a fourth, twelve-foot cryostat which together will add twelve resonators to the linac array. Also a superconducting debuncher-rebuncher is to be installed downline of the linac.

Acknowledgments

Of the many people at Argonne who have contributed to the linac project, the linac staff would particularly like to acknowledge the contributions of R. P. Breuss, A. J. Rogers and E. K. Gutowski in resonator construction, F. J. Lynch and R. N. Lewis in development of the pre-tandem bunching system, and R. T. Daly and J. E. Kulaga in implementing the computer-control system.

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DISCUSSION

J. Dick, Cal Tech: Could you describe the changes you made to increase the performance of the cavities in the accelerator cryostats and could you quantify the phase and amplitude jitter of the cavities in the actual accelerator configuration?

Shepard: We initially had some design problems in the cooling system; these have been cleared up - it has mostly been implementation. We have had some epoxy seals which gave us leak trouble. We had some plastic tubing which cracked early on but minor design changes seemed to have cured these problems. With respect to phase and amplitude jitter, the residual phase jitter is less than a degree peak-to-peak on the resonators. The amplitude control is good to a few parts in 10^4 at the present time.

D. Young, FNAL: Could you say a few words about the stability of the Niobium coating on the structures, especially with regard to repeated opening to atmospheric pressure?

Shepard: The thinnest Niobium in the system is a 16-tension Niobium sheet. Last summer we had a catastrophic vacuum accident which caused considerable degradation of 4 of the resonators. Other than that, we've not experienced degradation of the resonators in operation, either by re-cycling or by operation of the beam in 1800 hours of beam time.

J.P. Blewett, BNL: This technique for supressing vibrations I regard as a very considerable achievment, but it was not clear to me how you use the information from the rf to apply mechanical force to stop the vibration.

Shepard: The rf itself is coupled to the system. If you turn up the rf amplitude in one of these resonators, radiation pressure effects shift the eigen-frequency typically by several kilohertz, so that the rf mode and the acoustic modes are coupled. If you wiggle the rf amplitude at the resonant frequency of one of the acoustic modes, you can, for example, stimulate a vibration of the system. By sensing the vibration by watching the eigen-frequency of the resonator, you can detect the presence of a vibration and vary the rf amplitude in such a way as to damp the vibration itself. It is very weakly coupled, but the mechanical Q's are extemely high at these temperatures so the small damping has an appreciable effect. An electromagnet force is used to damp.

E. Jaeschke, Heidelberg: You mentioned some helium conditioning you had done in the June runs. How frequently did you have to do this and were these special cavities somehow nearer to the normal conducting outside world?

Shepard: Of the 8 resonators on-line, I think two of them would require conditioning perhaps every 48 hours and another one somewhat less frequently. The conditioning process itself requires about an hour to implement and so far we have found that we are required to do this periodically in order to maintain the full accelerating potential of the machine. It is our dominant source of downtime, but at the moment it does not seem to be a serious operating problem. It is less troublesome, let's say, than sparking in the tandem seems to be during operation.

L. Teng, FNAL: Were you able to observe any beam loading effect on the phase stability or phase lagging?

Shepard: No, we do not see that, but I should say that beam loading is a very small term in the rf losses of the system because of the very low beam current; it is a fraction of a watt and the dominant rf loss of 100 watts in the tuning system, I think, just completely blanks that out.

A. Citron, Karlsruhe: With respect to the question on beam loading; in our superconducting proton linear accelerator with helical structures, we went up to something like 200 μA and at that level the rf system feels the beam loading, but it can still manage.