# STATUS OF THE VARIABLE FREQUENCY HEAVY ION LINAC, RILAC

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## Summary

A variable frequency heavy ion linac is under construction at the Institute of Physical and Chemical Research (IPCR). The linac operates in $\pi$-$3\pi$ and $\pi$-$\pi$ modes and its acceleration frequency can be set between 17 and 45 MHz. The maximum energies of ions are 4 MeV/amu for light ions and 0.8 MeV.amu for heavy ions. The characteristics of the linac and the present status of the construction are reported in this paper. A plan for an energy booster of the linac is described.

## Introduction

RILAC under construction is a $\pi$-mode variable frequency heavy ion linac. It realizes efficient acceleration of a variety of ions by choosing the acceleration frequency according to the charge-to-mass ratios. Therefore the design of the resonators differs from that of fixed-frequency linacs. It consists of six quarter-wavelength resonators excited by six rf amplifiers separately[1]. The acceleration frequency can be set between 17 and 45 MHz. The construction work was started in 1975, and the installation of major equipment has been more than 90% completed.

In parallel with the installation work, several preparatory tests of individual elements of the linac, such as rf excitation of the cavity, beam acceleration by the injector, and a check of the injection beam line optics, were performed. Remaining installation work, such as the wiring of the control system, will be finished this year.

In this paper, mechanical and electrical characteristics of the linac, status and schedule of the construction work and a future project of the accelerator facility will be described.

## Accelerator Outline

Figure 1 shows a layout of the facility. Figure 2 is a photograph of the accelerator taken in the linac vault in June. The cavities have unusual shapes, as illustrated in Fig. 3, to meet the requirements of frequency variability and mechanical rigidity at the same time. Each of six rf amplifiers has two long stubs for impedance matching at the output stage. Owing to the stubs, the housing of the amplifier is very tall.

The injector terminal with a volume of 4×4 ×2.5 cubic meters is shown in Fig.4. Maximum acceleration voltage of the injector is 500 kV.

An example of energies of ions are listed in Table I. Those energies can be obtained without any charge stripping procedures. If it is necessary to save rf power, a charge stripper can be inserted between the fourth and the fifth cavities. Then the charge-to-mass ratio of the ions increases by a factor of three, which cuts the rf power dissipation in the following cavities by an order of magnitude.

Ten experimental sites are provided in three shielded rooms. Research proposals submitted cover many fields --- nuclear physics, atomic physics, solid state physics, radiation chemistry and biology. Requests for particle species, beam intensity and beam quality are varied. There is no plan of simultaneous multiple beams at present. The linac can be operated in a CW mode for most beams and, if a pulsed beam is desired, it can be produced by a chopper in the injection beam line.

Table I

| Ion | m/q | Accelerating RF freq. (MHz) | Voltage (MV) | Energy (MeV/n) |
|---|---|---|---|---|
| $^{12}C^{3+}$ | 4 | 45 | 16.5 | 4 |
| $^{20}Ne^{4+}$ | 5 | 39 | 16.5 | 3.1 |
| $^{40}Ar^{7+}$ | 5.7 | 39 | 18 | 3.0 |
| $^{84}Kr^{8+}$ | 10.5 | 31 | 20 | 1.9 |
| $^{132}Xe^{9+}$ | 14.7 | 25.5 | 20 | 1.36 |
| $^{238}U^{10+}$ | 23.8 | 20 | 20 | 0.84 |

## Resonators

As shown in Fig.3, the cavity is a quarter-wavelength coaxial resonator. It is made of copper-clad steel except for drift tubes. The resonant frequency of the cavities ranges from 17 to 60 MHz, but the uniformity of the acceleration voltage across each drift tube gap was found guaranteed only up to 45 MHz. Coarse frequency tuning is made by a movable shorting device, fine tuning by a large capacity compensator and very fine tuning by a small capacity compensator. The position of the shorting device is preset according to the velocity of the ions. The large compensator is used to accommodate the thermal tuning drift and the small one is coupled with a tuning error detector which automatically keeps resonance.

Figure 5 shows the frequency span and Q-values measured for some cavities. The distribution of the accelerating voltage and its frequency dependence were reported at the 1976 Linac Conference.[2] Two turbomolecular pumps (2400 ℓ/s and 5000 ℓ/s) are used in the vacuum system of each cavity and a final pressure of $3\times10^{-7}$ Torr has been achieved. In order to keep the vacuum clean, only welded bellows are allowed to introduce mechanical motion into the cavity.

## Drift Tubes

Every second drift tube is electrically connected to the outer conductor of the cavity. The drift tubes have outer diameters of 160 mm and contain quadrupole magnets. They are supported by a hollow beam of square cross-section. Electric current and coolant are fed to the quadrupole magnets through the inside of the beam. The drift tube shell is made of oxygen-free copper, electron beam-welded.

Alignments of the magnetic axis of the quadrupole magnets were measured by the hot-wire method.[3,4] Accuracy of the alignment is within 0.1 mm.

Two types of coils are used for the quadrupole magnets : tape coil type and quadrant stacked type. The maximum power consumption of a quadrupole magnet is 600 W at 7 kG/cm for pole tip distance of 23 mm. The smallest beam aperture is 20 mm.

The other drift tubes attached to the inner conductor of the cavity are made of solid copper and water-cooled. The outer diameter of them is 100 - 160 mm and no quadrupole magnets are set in them. Figure 6 is the view of the drift tube array seen from a cavity window.

## Radio-Frequency System

Figure 7 is a block diagram of the amplifier system. The first amplifier was constructed and tested from 17 to 40 MHz with a water-cooled resistive load and then from 20 to 30 MHz with the first cavity coupled through a feeder, in January 1979. The first rf system drove the cavity through the multipactoring region within two hours after the start-up and about 80% of designed voltage was achieved a few days later. For the amplifier test, a temporary plate power supply and cooling system were used, which were then removed and replaced by permanent units in the spring of 1979. The remaining five amplifiers and power supplies were manufactured by vendors with some modifications found necessary by the power test of the first unit. The installation of the amplifiers and related power supplies began in April and was finished in August. The power feeders are scheduled to be installed in September and will be completed in the middle of October 1979.

The rf tuning, phase and amplitude in each unit are controlled locally by hard-wired feedback circuitry. The positions of the shorting device, capacities and stubs are preset by the control system computer at the beginning of each machine time. The reference values of the phase and amplitude are given by the computer. The hardware for automatic feedback and interface to the computer system are now under fabrication.

## Control System

The control system uses a minicomputer HP2171A and the IEEE-488 Interface Bus (GP-IB). As the interface between the accelerator and the computer, four data stations are installed in the linac vault and one in the control room. Those in the linac vault are connected to the computer by a serial data link and GP-IB. A control console with two CRT's is used for the man-machine interface.

The installation of the control system started in June and will end in October 1979. Figure 8 shows a block diagram of the control system.

## Beam Test

At present, acceleration tests of the injector and studies of the injection beam line optics are performed using singly charged ions of H, N, and Ar. An axial extraction PIG ion source installed in the injector terminal is used for the tests. A side extraction PIG ion source to produce multiply charged ions will be usable from next spring. Beam acceleration tests with the first rf system were started in September using $N^{1+}$ ions.

## Schedule of Construction and Operation

Those remaining items of the linac to be installed and debugged before starting acceleration tests are the control system, beam buncher, beam attenuator and beam monitoring devices. At present, it is supposed that minimum conditions to begin acceleration tests will be satisfied at the end of October 1979. Acceleration tests are planned to continue until spring 1980 and then use of the facility for research will begin.

## Plan for Future Extension of the Facility

Since the energies of heavier elements ($A \gtrsim 50$) are insufficient for the study of nuclear reactions, an energy booster for RILAC is being proposed.[5] Our intention is to build a separated sector cyclotron as a post-stripper accelerator and to amplify the energy of ions by a factor of roughly twenty. Figure 9 is a layout of the proposed facility and Table II gives tentative characteristics of the cyclotron. The parameters of the RF systems of both machines can be well synchronized owing to the frequency variability of the linac. If approved, the facility will be a powerful tool for multidisciplinary research.

Table II

Characteristics of proposed cyclotron

| | |
|---|---|
| Maximum Energy for $U^{37+}$ | 15 MeV/n |
| Maximum Energy for $C^{6+}$, $Ne^{10+}$ | 80 MeV/n<br>(120 MeV/n)* |
| Number of Sectors | 4 |
| Sector Angle | 50° |
| Injection Beam Radius | 78 cm |
| Extraction Beam radius | 338 cm |
| Number of Dees | 2 |
| Peak Voltage | 250 kV |
| RF Frequency | 17-45 MHz |
| Number of Harmonic Acceleration | 4*, 6*, 8, 12 |

* An AVF cyclotron used as an injector for light ions.

## References


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2. M. Odera, Proc. 1976 Proton Linear Accelerator Conf., 62 (1976).
3. R. M. Main, LBL-1224, Sept. (1972).
4. I. Takeshita, I. Yokoyama and T. Kambara, Reports I.P.C.R. (in Japanese) 53, 44 (1977).
5. H. Kamitsubo et al., IEEE Trans. Nucl. Sci. NS-26, 2070 (1979).

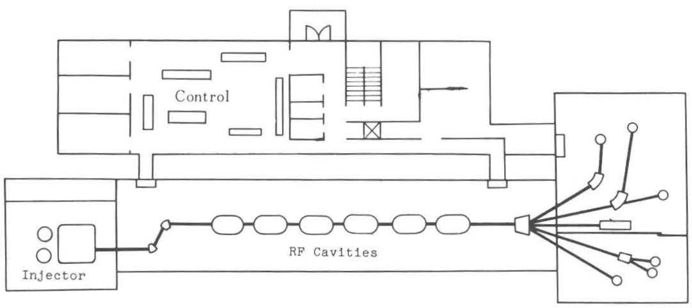


Fig.1. Layout of the RILAC facility.

Fig.2. RILAC seen from upstream side.

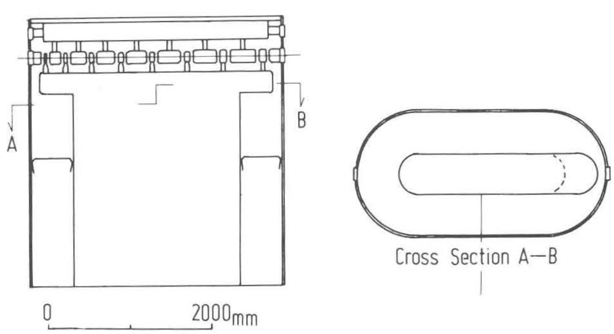


Fig.3. Resonator schematics.

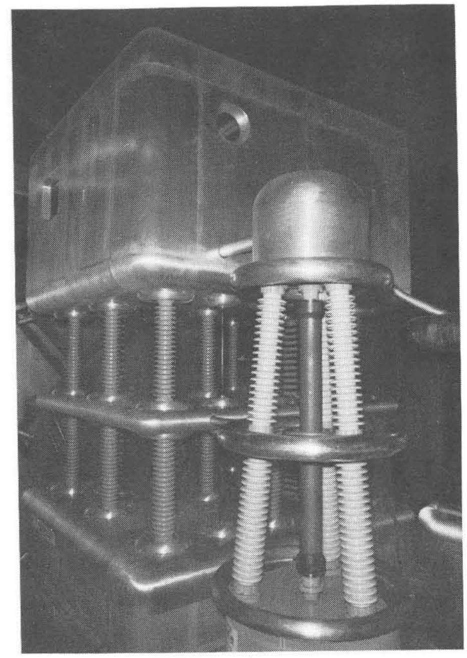

Fig.4. High-voltage terminal of the injector.

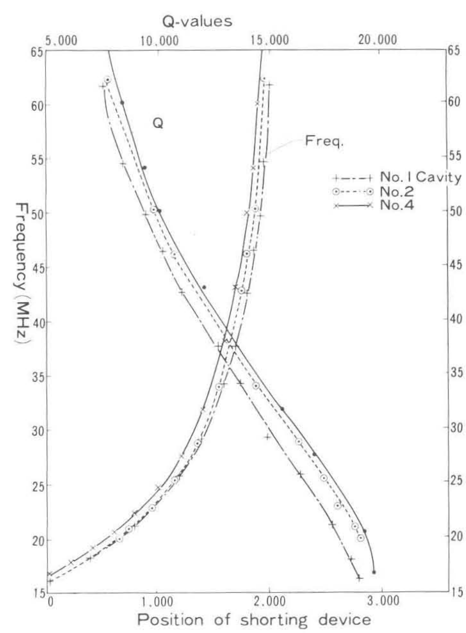


Fig.5. Characteristics of resonators.

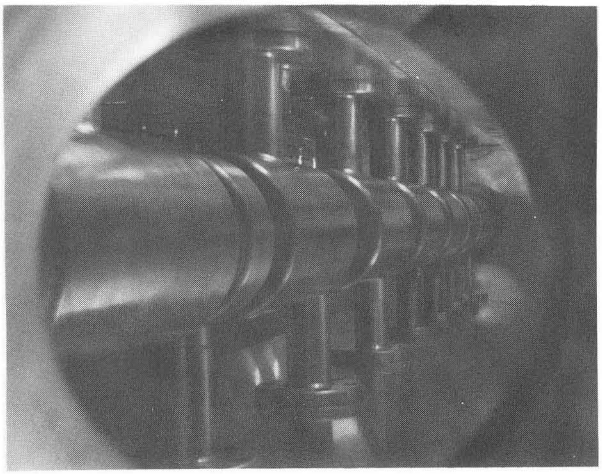

Fig.6. Drift-tube array.

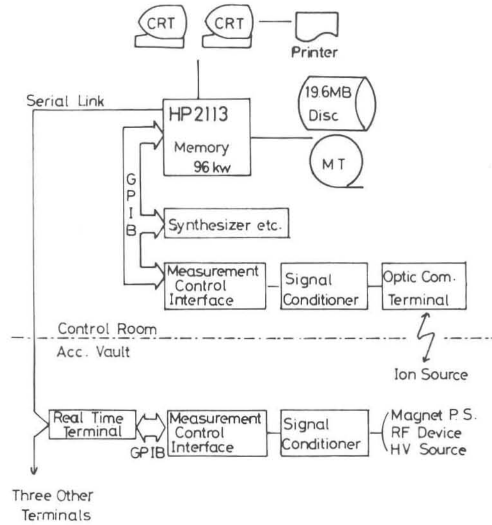


Fig.8. Control system.

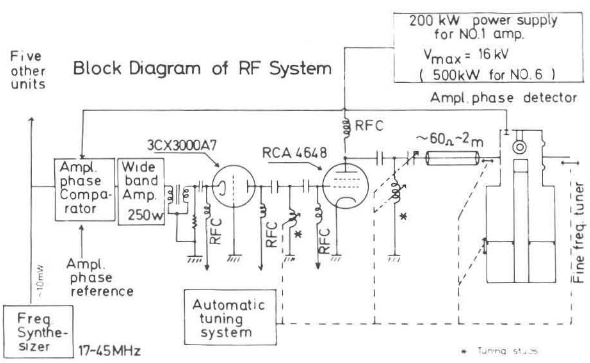


Fig.7. Block diagram of the power amplifier.

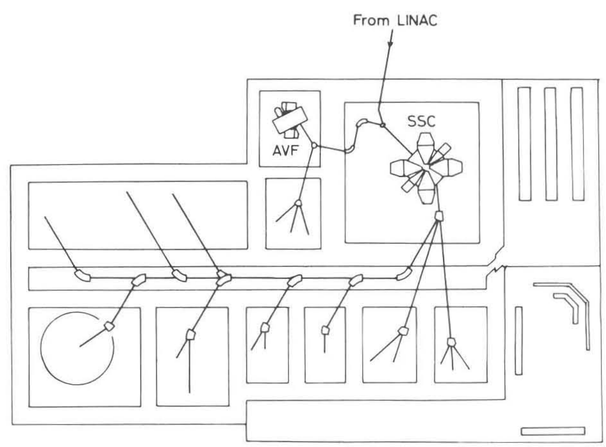


Fig.9. Proposed facility layout.