# OPERATION EXPERIENCE OF THE RIKEN VARIABLE-FREQUENCY HEAVY-ION LINAC, RILAC

M. Kase, M. Odera and Linac Operation Group*

Linac Laboratory, Inst. Phys. and Chem. Research
2-1, Hirosawa, Wakoshi, Saitama
351 JAPAN

## Summary

The RILAC, the variable-frequency heavy-ion linac, which will be used as an injector to the separated sector cyclotron, has provided useful beams to experimental groups. The frequency range available now is 18 - 30 MHz. The upper limit is determined by the parasitics mode at 35 MHz in the rf system. The beam energy can be varied in a wide range by changing the beam phase without degrading the beam quality so much.

## Introduction

The variable frequency linac, RILAC, was originally proposed in 1972, as a part of a complex heavy-ion accelerator facility to extend the research which had been pursued by a heavy-ion cyclotron.[1] The cyclotron which began operation in 1966,[2] was being in use on 168 hours a week basis and there were desires among the users in 1970 already for extension of research possibility by increasing energies or ion species in 1970 already.

A few years after the submission of the proposal, only a prestripper-part which is the RILAC was approved, and construction was started in 1975. In order to realize our aim for acceleration of every elements in the periodic table without demanding too much to the ion source technology, we decided to develop the variable frequency linac scheme[1,3]

Construction of the accelerator was completed in 1980. Trial acceleration by the first cavity was made in September of 1979 and by six cavities which compose the whole linac, in autumn 1981. Experiments by beam began from fall of 1981.

Meanwhile, the remaining part of the 1972 proposal, a separated sector cyclotron was approved in 1980. Design and construction work is being undertaken by the annex laboratory of ours, cyclotron laboratory, and the four sector magnet of the poststripper accelerator will be installed next to the linac building in spring of 1984.

RILAC is by itself being actively used for atomic and solid state physics study at present. Table 1 gives a rough outline of the linac. Fig.1 shows a plan view of the facility layout. This paper gives operation statistics and some experience obtained in operation of the linac such as beam diagnosis, energy tuning, RF phase excursion etc.

**Table 1** Outline of the RILAC

| | |
|---|---|
| Special feature; | Frequency variable |
| Frequency range; | 17 - 45 MHz |
| Charge to mass ratio of ions; | > 1/27 |
| Energy per nucleon; | 4 MeV/n for q/A =1/4 |
| | 0.8 MeV/n for q/A =1/20 |
| Energy tuning; | Continuous down to 10 % |

## Operation statistics

Fig.2 shows distribution of ions used in 1982 in the energy and effective accelerating

* Y.Chiba, Y.Miyazawa, M.Hemmi, T.Tonuma, T.Inoue, T.Kambara, M.Yanokura, T.Kubo and E.Ikezawa

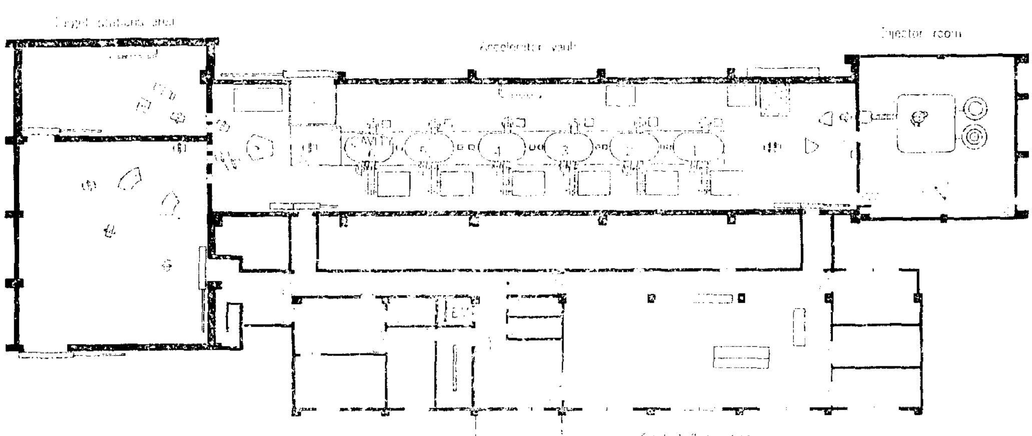

**Fig.1** The RILAC facility.

0018-9499/83/0800-3033$01.00©1983 IEEE

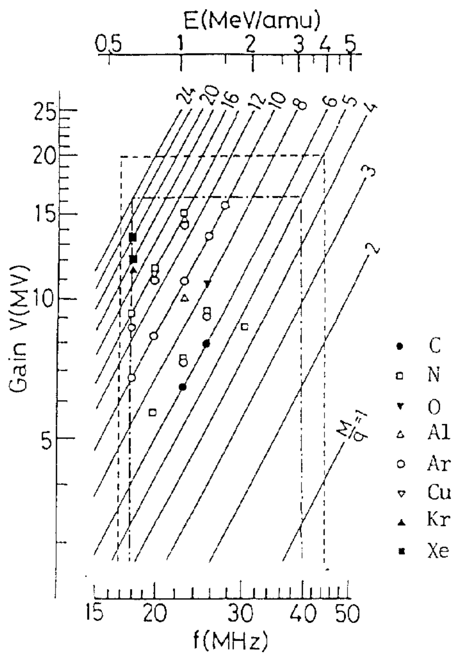


**Fig.2** Distribution of ions accelerated in 1982

voltage diagram. Specification of the RILAC is within the square in that figure. Parameter is the mass-to-charge ratio of ions. Largest user at present is people of atomic physics and the next is material science. Table 2 gives ratio of machine time used for experiments, accelerator development and others. Use of ions is still concentrated to argon ions, though gradual increase of demand for heavier projectiles is expected.

## Radiofrequency system

It takes one to two hours to change the acceleration frequency depending on the frequency or its difference from the previous one. Since the automatic parameter setting system cannot be used by the reason given below, some parameters such as positioning of the tuning stubs of the plate and control grid of the power tubes must be made manually. There still remains a parasitic mode at around 35 MHz. The plate and grid circuits tuning has to be made a little staggered to avoid excitation of the unwanted mode. The amount of detuning depends on how far the wanted frequency removes from the parasitics. Of course, the deviation may be included in the control programming. However, the detuning method lowers the power efficiency of the power amplifier. A few proposals to cure this problem have been made and are under investigation.

Multipactoring phenomenon rarely makes trouble except at the time after the prolonged vacuum discharge. Gases released by sparking seem to make the phenomenon appear. By stopping excitation of the cavity for a few

**Table 2**
Operation Statistics of the RILAC in 1982

Total operating time 1640 hr.

| | | | |
|---|---|---|---|
| $C^{2+}$ | 0.85% | $Ar^{2+}$ | 1.9% |
| | | $Ar^{3+}$ | 15.8% |
| $N^{+}$ | 6.8% | $Ar^{4+}$ | 49.8% |
| $N^{2+}$ | 8.5% | $Ar^{6+}$ | 1.2% |
| $N^{3+}$ | 0.64% | | |
| | | $Cu^{4+}$ | 0.55% |
| $O^{2+}$ | 0.18% | $Cu^{5+}$ | 0.85% |
| | | $Cu^{6+}$ | 0.06% |
| $Ne^{2+}$ | 0.39% | | |
| | | $Kr^{5+}$ | 1.8% |
| $Al^{2+}$ | 1.6% | $Kr^{6+}$ | 1.6% |
| $Al^{3+}$ | 0.18% | | |
| | | $Xe^{7+}$ | 2.6% |
| | | $Xe^{8+}$ | 0.58% |

minutes, restart can be made easily. However, the thermal equilibrium of the cavity being a little displaced by the cool down, a small shift of parameters becomes necessary in that case. It takes a few minutes more to regain former state. A simple circuit was fabricated and added in the amplifier chain, which immediately cut off the excitation of the cavity as soon as disappearance of the high frequency voltage in the cavity is detected. After hundreds of micro-seconds of which value is adjustable, it enables pulsive excitation and watch cavity field. If the field is seen established in the cavity, pulse length is made infinitive, or normal excitation mode is resumed. Otherwise, excitation is stopped for another interval. By cutting off RF within a few microseconds, gas generation becomes minimum and restarting is almost instantaneous, making operator work easier.

## Energy tuning

To meet the request of many applications for different energies, the beam energy can be varied by changing the following factors:

1) the number of cavities in use (1 to 6);
2) the acceleration frequency;
3) the input phase of beam bunch to the last cavity.

The first scheme is normally used in multitank linacs, which provides six discrete energies for a given frequency in case of the RILAC. When the second scheme is used together with the first one, the energy can be changed over a wide range of 0.1 - 4.1 MeV/n. However, to operate the linac with the change of the frequency, most of the parameters of the linac including its injector system have to be readjusted and it takes much time to do this. For the frequent change of energy by fine steps, the third scheme (that is the phase control) is more useful than the above, by combining it with the first scheme the energy is variable over a wide range.

Let #N denote the cavity used for the control, i.e. the last cavity among those in use. The injection phase of beam relative to the rf voltage at the first acceleration gap of cavity #N is shifted from the synchronous

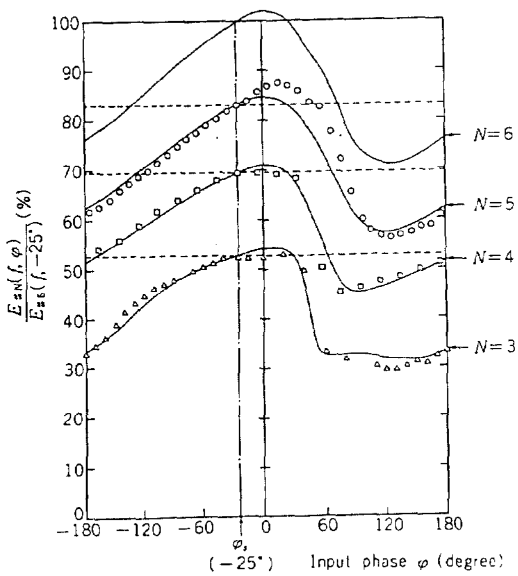


**Fig.3** The variation of beam energy vs the input beam phase of the "last" cavity (#N). Energy is normalized to the designed value at the cavity #6, Ø.ØØ2Ø2xf$^2$ (MeV/n) where f is the frequency in MHz.

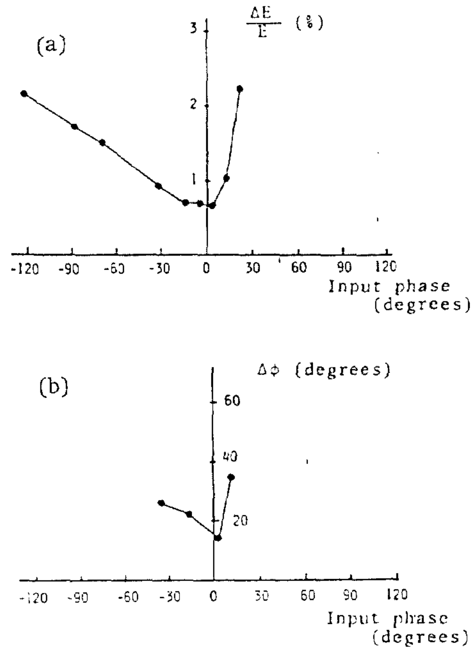


**Fig.4** Experimental result of energy spread (a) and bunch width (b). These data are obtained with SSD.

phase(-25 deg.). Fig.3 shows the variation of energy with the change of the injection phase. The solid lines in the figure are the results of the calculation (for n = 3,4,5 and 6) which is made using the impulse approximation[5]. The experimental results are also shown in Fig.3 for N = 3,4 and 5.

Using the phase control, the beam energy of the cavity in concern can be decreased smoothly down to the level lower than that of the input energy. It can be expected that the use of the phase control together with the first scheme provides the continuous energy change in the wide range without varying the frequency. The procedure to change the energy in this way is much simpler than those including the change of frequency, because the operator has to adjust no parameter in the portion from the injector to the cavity #(N-1), but only the rf phase of the cavity #N and parameters in the latter portion of the linac.

It is possible that the frequency is determined, independently of the energy in concern, only taking account of the M/q value of ions to be accelerated. In any case, there is no need of the exact frequency setting for each energy.

## Beam quality

It is interesting to know how the beam quality changes when the injection phase is shifted. Fig.4(a) shows the energy spread of the beam at the exit of the cavity #5 vs the injection phase of the same cavity. The energy spread has a minimum (Ø.6% fwhm) when the input phase is Ø deg.. The change of the energy spread in the positive phase region is much larger than that in the negative phase region. This fact is consistent with the shape of the curve in Fig.3. The bunch width vs the input phase is shown in Fig. 4(b). The bunch width has also a minimum (12 deg. fwhm) when the phase is zero. Emmitance is around 15 mm mrad in the normal operation. It gradually increases when the input phase is shifted from the synchronous phase and reaches 25 mm mrad at -12Ø deg..

## Conclusion

The RILAC has begun operation and no serious difficulty has been encountered except the parasitic mode at 35 MHz. It is expected that parameter setting and tuning can be made nearly automatic after the parasitics are removed. Beam transmission through the first cavity is almost 6Ø% and 2Ø to 3Ø% through six cavities. Improvement of the total efficiency upto the value of the first cavity is expected to be achieved presently.

## Reference


1) M. Odera and T. Tonuma: Proc. Sixth Interna. Cyclotron Conf. 1972 Vancouver, AIP Conf. Proc. No9 p283 (1972).

2) M. Odera et al.: Sci. Papers Inst. Phys. Chem. Res., 67 99 (1975).

3) M. Odera: Proc. 1976 Linear Accel. Conf., 1976 Chalk River, AECL 5677 62 (1976). M. Odera, Y. Chiba and T. Kambara: Proc. 1979 Linear accel. Conf. Montauk, BNL 51134 28 (1981).

4) H. Kamitsubo: Proc. Ninth Interna. Conf. on Cyclotrons and their Application, 1981 Caen, 13 (1981).

5) T. Tonuma, F. Yoshida and M. Odera: Report IPCR(in Japanese) 51 p.53 (1975).