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STATUS REPORT ON RIKEN RING CYCLOTRON

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ABSTRACT

On December 16, 1986, the first beam was successfully extracted from RIKEN Ring Cyclotron (RRC). After the scheduled two-month overhaul from the end of January, 1987, the machine studies were performed in April and May. Beams have been delivered to the experiments since the end of May. The maximum beam intensity reached 200 enA for both $^{40}Ar^{12+}$ at 21 MeV/u and $^{14,15}N^{6+}$ at 33.7 MeV/u; 10 enA for $^{65}Cu^{18+}$ at 16.7 MeV/u during these runs. The pulse width of the extracted $^{40}Ar^{12+}$ beam of 21 MeV/u was measured to be 700 ps at the position 20 m downstream from RRC. The facility and its present status are described as well as the running construction program of the new injector, a K70 AVF cyclotron with an external ECR source.

1. INTRODUCTION

Detailed descriptions of RIKEN Accelerator Research Facility (RARF) have been given previously[1]. In November, 1986, a K540 four-sector ring cyclotron (RRC), an injection beam transfer line from the heavy-ion linac (RILAC), and an extraction beam transfer line to E1 experimental hall were completed. The injection beam transfer line is equipped with a carbon-foil charge stripper and a rebuncher.

The first operational trial of this accelerator complex was started on November 28. An $^{40}Ar^{4+}$ beam of 1.28 MeV/u from RILAC passed through the charge stripper, and the 12^+ charge state of the beam was selected, and injected to RRC on December 3. On December 16, the $^{40}Ar^{12+}$ beam of 21 MeV/u was successfully extracted from RRC only 13 days after the beam injection. The acceleration was performed with a harmonic number of 10 insread of 9 (normal operation). This harmonic number was adopted because RILAC was operated with five resonators except the last (sixth) one, the rf amplifier of which had been disassembled for the improvements.

The routine operation of RRC was started in April, 1987. It is made every other week: one week for RRC and the other for RILAC experiments. April and May were devoted to the machine studies, and the beams have been delivered to the experiments since the end of May.

2. INITIAL OPERATING RESULTS

2-1. Accelerated beams

So far four kinds of ions were used for experiments. The main characteristics of these beams are summarized in table 1.

Table 1

Characteristics of accelerated beam.

		^{40}Ar	$^{14,15}N$	^{65}Cu
RF frequency	MHz	28	35	25
RILAC				
Charge state		4^+	3^+	5^+
Beam energy	MeV/u	1.28	2.00	1.01
Bunch length (full beam)	RF deg.	~15	~15	~15
Rad. emit. (full beam)	mmmrad	~10π		
Vert. emit. (full beam)	mmmrad	~10π		
RRC				
Charge state		12^+	6^+	18^+
RF harmonic number		10	10	10
RF voltage	kV	~150	~150	~150
Beam energy	MeV/u	21.0	33.7	16.7
Extracted beam intensity (typical)	enA	200	200	10
Energy spread (FWHM)	10^{-3}		~4	
Bunch length at extraction (FWHM)	RF deg.		~4	

2-2. Beam transfer line

The beam from RILAC passes through the charge stripper (a 10 μg/cm^2 thick carbon foil) which is placed immediately after RILAC, and is deflected by an angle of 25.7 degrees with a couple of dipole magnets. A single charge state of the beam is selected by a slit after these magnets. The power supplies for quadrupole magnets on the beam line are set to the values expected from the TRANSPORT calculation based on the measured beam emittance. On the other hand, currents for the matching-section quadrupole quartets are readjusted to make the measured beam profiles as expected.

Steering corrections being achieved, the buncher is switched on. Its RF voltage is kept at the calculated value, while its RF phase is carefully tuned. The correct RF phase is obtained when the beam central phase detected at the end of line does not change with the buncher being on or off.

The beam transfer efficiency after the charge selecting slit was more than 80%.

2-3. RRC

Sector magnet fields of RRC are precisely cycled to keep the field-setting reproducible. Approximately two hours are necessary for this procedure[2].

The power supplies for the beam injection system are adjusted so that the beam is centered at the entrance of each injection element. The position of the beam is monitered by a four-segment buffle slit placed in front of each element[3].

Initial settings of RF phases are determined to obtain maximum separation of first several turns which is measured by a 2.5 m stroke radial differential probe.

By changing only the main-coil current slightly, a preliminary adjustment of the sector field is made. This is done untill all twenty pairs of nondestructive capacitive phase pick-up probes covering the region from the injection to the extraction detect timing signals of the beam. The sector field obtained by this procedure is not always the optimum isochronous field as shown in fig.1. Formation of the isochronous field distribuiton is performed according to the following procedure: (1) measuring the beam phases with the phase probes, (2) calculating the field deviation from the desired isochronous field, and (3) setting the optimum values of the main and trim coil currents given by the procedure described in ref. 4. Usually a sufficient field distribution is obtained after three trials as shown in fig.1.

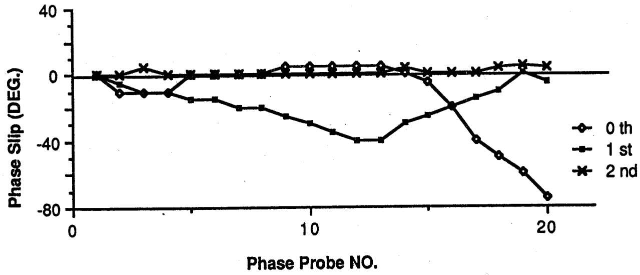

Fig. 1 Beam phases measured with phase probes.

The three-probe method previously described in ref. 5 allows not only the observation of betatron oscillations but also the measurement of closed orbit off centering. Field unballance between four sector magnets can be measured and corrected according to the data of two-dimensional position of closed orbit center obtained with this method. Figure 2(a) shows the movement of the orbit center due to the incomplete setting of the injection condition and the unballance of the sector field. Good orbit centering is achieved by adjusting the position and voltage of the electrostatic inflection channel, ballancing the four sector fields, and correcting trim coil currents to remove local residual field imperfections (shown in fig. 2(b). Figure 3 shows the well-centered turn pattern measured by the main differential probe.

In the beam-service runs for the users, well-centered orbit operation is not performed, but off-centering acceleration is made to save the beam preparation time and to expand the turn separation in the extraction region. Before the beam extraction, the RF phase is readjusted to obtain clear turn patterns in this region as shown in fig. 4. The power supplies for the beam extraction system are adjusted in the same way as the beam injection. Single turn extraction is achieved.

The beam tansfer efficiency for RRC was typically 30% up to now. Most part of the beam loss in RRC takes place through the injection system.

The beam extracted from RRC focuses typically by the size of 4 mm$^{\phi}$ at the object point 3.3 m downstream from RRC, and is transfered to the experimental setup located in the E1 hall.

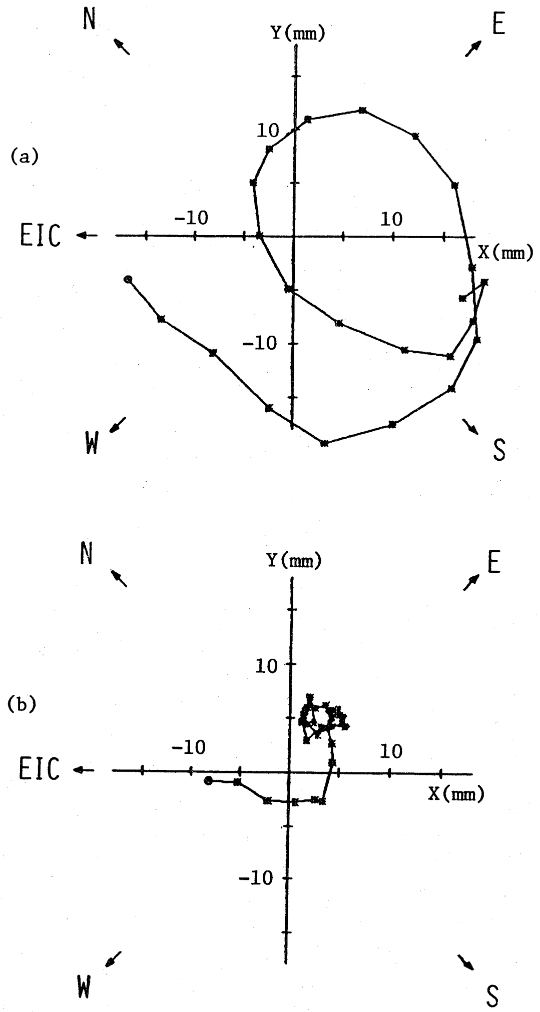

Fig. 2 Movement of the orbit center measured with three-probe method.

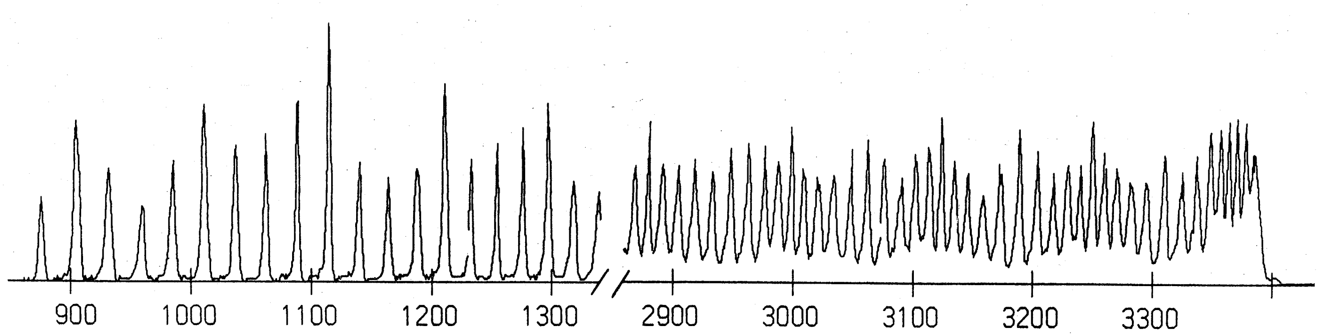

Fig. 3 Well-centered turn pattern measured by a main differential probe.

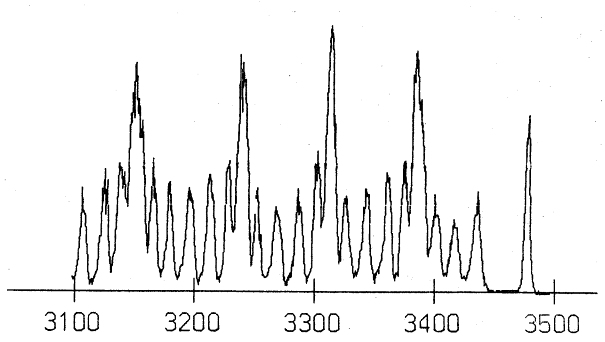

Fig. 4 Turn pattern at the extraction region in the case of off-centering acceleration.

3. FUTURE BEAMS AND EXPERIMENTAL APPARATUS

Upgrading of the RARF beam energy is scheduled in four stages.

1. After the scheduled maintenance in this summer, RILAC goes into the six resonator operation. RRC works with harmonic number of 9, and the beam energy of $^{14,15}N$ and ^{40}Ar is increased up to 42 and 26 MeV/u, respectively.
2. The effective acceleration voltage of RILAC will be increased to 16 MV for the whole frequency range of 20-45 MHz in the beginning of 1988. This will allow the maximum beam energies for N, Ar, Kr and Xe ions of 60, 41, 23 and 17 MeV/u, respectively.
3. The K70 injector AVF cyclotron equipped with the external ECR ion source will be completed at the end of 1988 FY. Protons and ^{3}He ions will be accelerated to 210 and 185 MeV/u, respectively. The maximum energy of 135 MeV/u corresponding to the maximum magnetic rigidity of RRC will be attained for light heavy ions up to Si, and 95 MeV/u for Ar.
4. At the end of 1989, an ECR ion source will be installed on RILAC. The final energy of heavy ions will be substantially increased. The maximum energies for Kr, Xe and Au are expected to be 56, 42 and 26 MeV/u, respectively.

Experimental apparatus in E1, E2, E3 and E7 halls will be installed in coming spring. RARF is scheduled to be fully completed as shown in fig. 5 at the end of March, 1989.

REFERENCES

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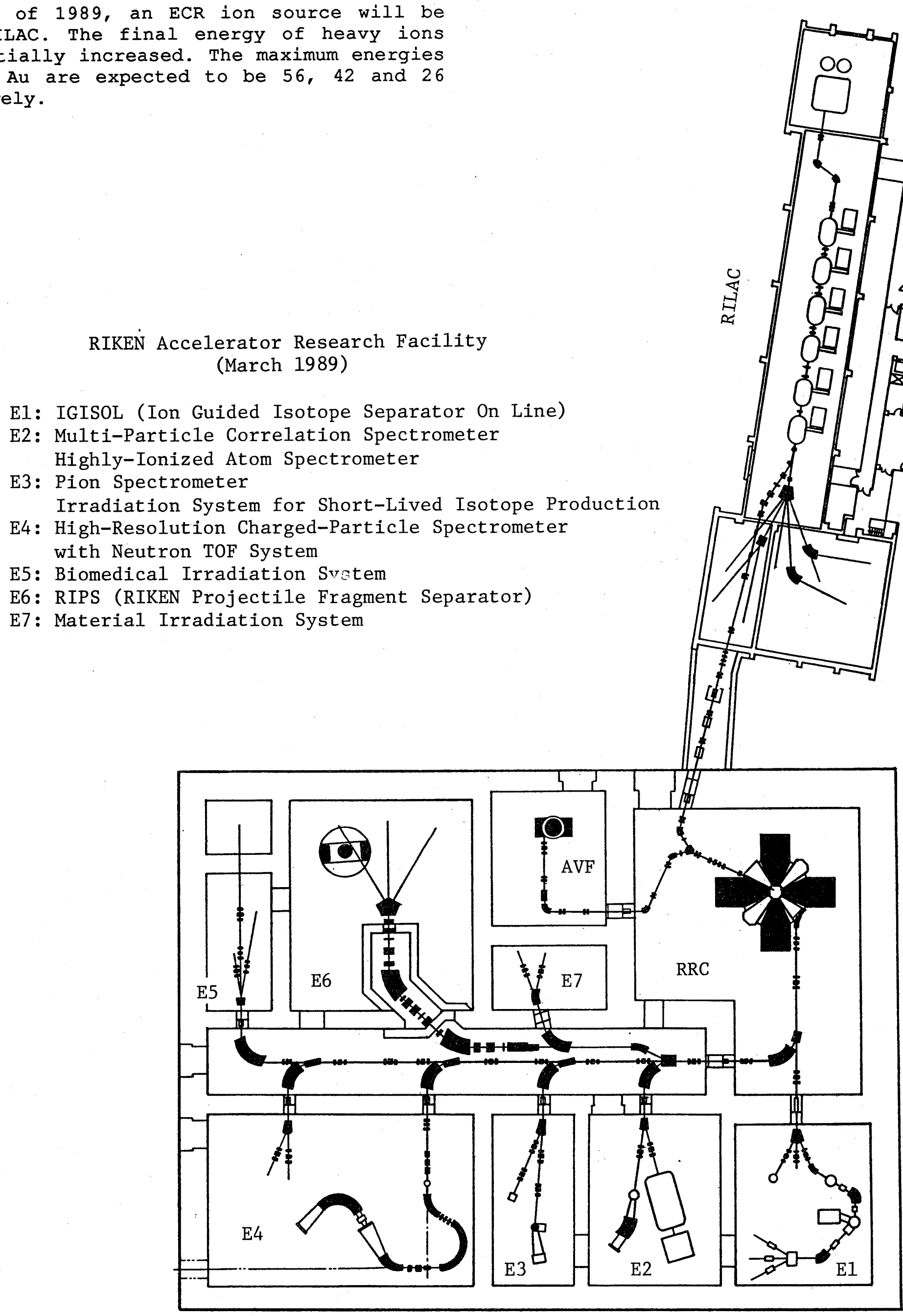

Fig. 5 Plan view of RIKEN Accelerator Research Facility.