IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

STATUS REPORT ON THE RIKEN RING CYCLOTRON

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Summary

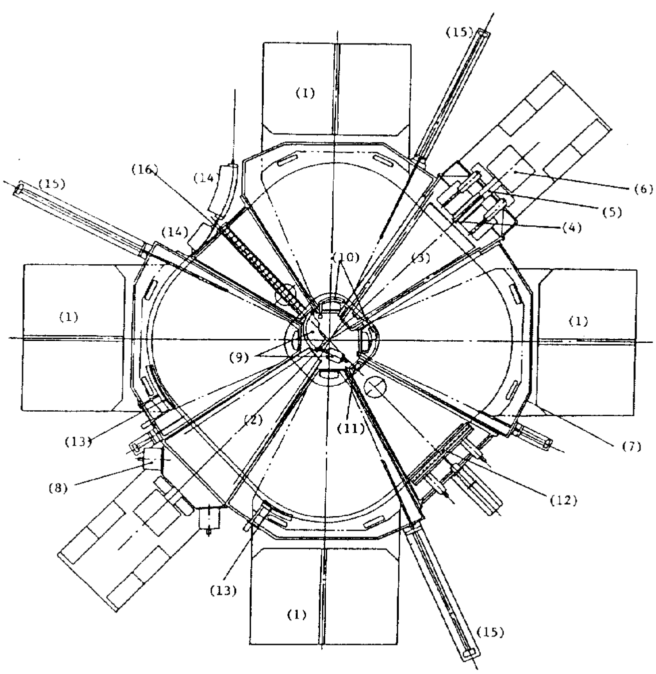
The RIKEN ring cyclotron (separated sector cyclotron), combined with two injectors, can accelerate all elements from proton to uranium up to energies between a few tens of MeV/u and a hundred MeV/u. Construction of this cyclotron is well under way according to schedule. All of the sector magnets were installed in the cyclotron vault in June of 1984. The remaining components are being under fabrication at the factory. Orbit analysis is also under way to find out how to operate this machine easily. The ring cyclotron will be completed in the beginning of 1986 and the first beam is scheduled for the fall. Present status of the RIKEN ring cyclotron is reported.

Brief Description

We described the RIKEN ring cyclotron project previously (1). The ring cyclotron is a main accelerator of the RIKEN heavy-ion accelerator complex having two injectors, one of which is the variable frequency heavy-ion linac (RILAC) and the other an AVF cyclotron with K-value of 65 MeV. RILAC is principally used for the acceleration of heavy ions with mass-to-charge ratio A/q>5 while the AVF cyclotron for light ions with A/q<5.

Table 1 lists the characteristics of the beam from the ring cyclotron expected; calculation of the beam dynamics was reported (2). Energy resolution, emittance and time resolution are estimated by taking the actual quality of the beam from the RILAC into account. A plan view of the ring cyclotron is shown in Fig. 1 and its principal parameters are listed in Table 2.

Construction of the ring cyclotron started in 1981; its schedule is shown in Fig. 2. The ring cyclotron will be completed in the beginning of 1986 and the first beam is scheduled for the fall. Construction of the AVF cyclotron will be initiated from 1987.



(1) SECTOR MAGNET (2) RF RESONATOR (3) DEE
(4) COUPLER (5) FEEDER (6) AMPLIFIER
(7) VACUUM CHAMBER (8) CRYOPUMP (9) BENDING MAGNET
(10) MAGNETIC CHANNEL (11) ELECTROSTATIC CHANNEL (12) ELECTROSTATIC CHANNEL
(13) MAGNETIC CHANNEL (14) BENDING MAGNET (15) RADIAL PROBE
(16) PHASE PROBE

Fig. 1. A plan view of the RIKEN ring cyclotron.

Table 1. Characteristics of the beam from the ring cyclotron.

Maximum energy per nucleon	
proton	210 MeV
^{3}He	185 MeV/u
deuteron, alpha	135 MeV/u
Heavy ion	540 $(q/A)^2$ MeV/u
Energy resolution	0.05 %
Emittance	1.25π mm·mrad
Time resolution	200 ps

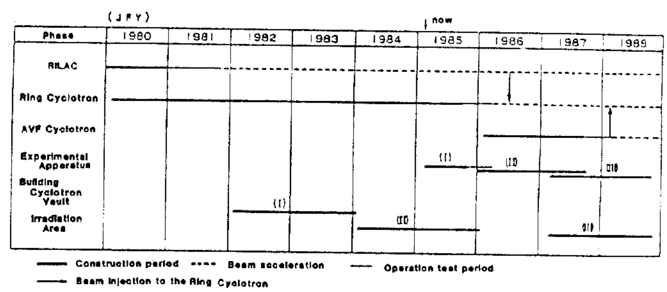


Fig. 2. Construction schedule of RIKEN accelerator facility.

Table 2. Principal parameters of the ring cyclotron.

Number of sector magnets	4
Sector angle	50°
Gap width	8 cm
Maximum field	16.7 kG
Maximum power	700 kW
Number of trim coils	29 × 4 pairs
Total weight	2100 ton
Number of dees	2 (λ/2 type)
Dee angle	23.5°
RF frequency range	20 – 45 MHz
Frequency tuning	Movable box and Trimmer
Maximum RF voltage	250 kV
Maximum power	600 kW
Main evacuation system	10^4 ℓ/s cryopump × 10 5×10^3 ℓ/s cryopanel × 4
Pressure	$< 1 \times 10^{-7}$ Torr
Control system	Computer network and a number of micro-computers
Dimension of the SSC	
Diameter	12.6 m
Height	6 m
Mean injection radius	0.893 m
Mean extraction radius	3.56 m
Orbit frequency	1.8 – 7.37 MHz
Harmonic number	
RILAC – injected	9, 10, 11
AVF – injected	5

Sector Magnets

Main characteristics of the sector magnet are also given in Table 1. Preliminary results of measurements of the magnetic characteristics and field distribution were already reported (3). Assembling of the sector magnets were finished in June, 1984. Figure 3 shows a photograph of the sector magnets which were installed in the cyclotron vault.

Two power supplies are used for main coils and nine power supplies having seventy-two output terminals are used for trim coils. Measured stabilities during eight hours were 2×10^{-6} and 5×10^{-5} for main coil and trim coil power supplies, respectively.

The field measurement was started in February, 1985. Optimum procedures were investigated to ensure a fast setting and a good reproducibility of the magnetic field. It usually takes more than one hour to magnetize the large ion mass completely. Relative field distributions of the four sector magnets are nearly the same but their absolute field levels are different within 1.5×10^{-3} at 15.5 kG. This value is caused by differences in steel properties and mechanical deformation of the pole gap due to magnetic force. In order to accomplish the procedures for setting desired isochronous fields, the measurement of the trim coil field distribution is in progress.

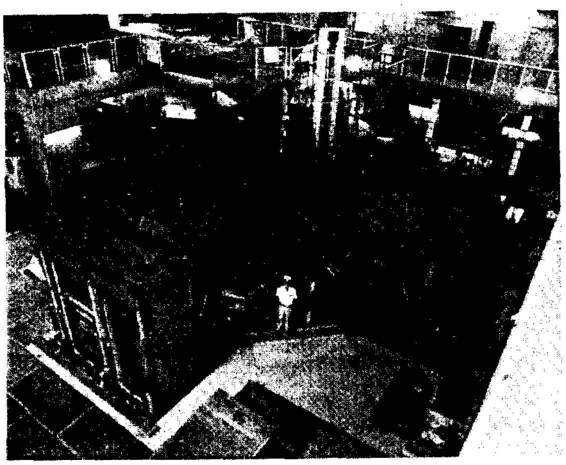
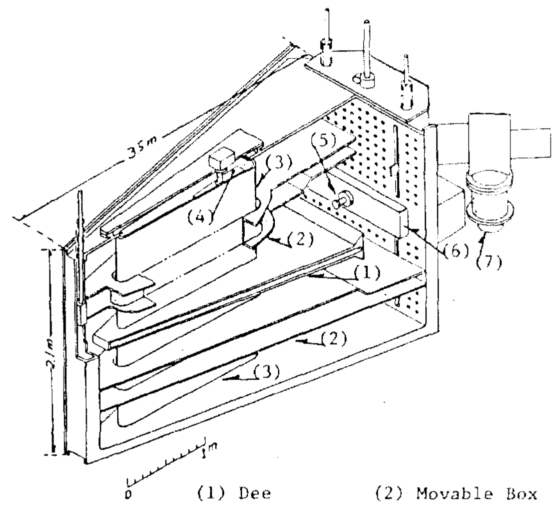


Fig. 3. A photograph of the sector magnets which were installed at the due position in the cyclotron vault.

RF System

The RF system is required to satisfy the conditions as the frequency range is 20 to 45 MHz and energy gain per turn per unit charge is 1 MeV. The resonator was designed based on the calculation and the model test (4). Figure 4 shows a bird's-eye view of the RF resonator. Total height of the resonator is 2.1 m. The outside enclosure and inner stem are made of copper-cladded stainless steel which has many cooling channels engraved on the surface of stainless steel beneath the copper overlay. A relation between RF voltage and frequency for the resonator is shown in Fig. 5. The solid curves correspond to the RF voltages at the extraction and injection radii. The broken lines show the RF voltage needed to realize 8 mm turn separation at the extraction radius for several ions.

Master oscillator and power amplifier system is to be employed for an RF oscillator system. High stability of RF voltage as well as its phase is also required. The RS2042SK tube is used in grounded grid configuration. The plate circuit is a quarter wave-length type stub and tuned by changing the length of the stub. The cathode tuning circuit is also a quarter wave-length type stub and tuned by a variable capacitor. Structure of the final amplifier and its tuning characteristics were investigated on a full-sized model with the RS2042SK tube.



(1) Dee (2) Movable Box
(3) Stem (4) Cryopanel
(5) Coupler (6) Trimmer
(7) Vacuum Pump

Fig. 4. A bird's-eye view of the RF resonator.

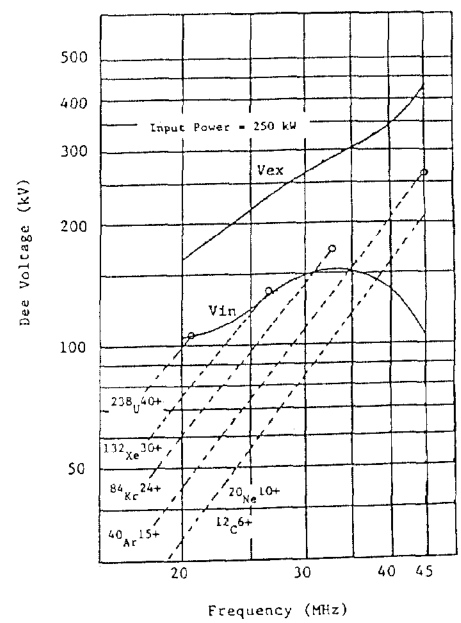


Fig. 5. Dee voltage estimated by the model test for the input power of 250 kW. Vex and Vin are voltages at the extraction and injection radii, respectively.

Vacuum System

The vacuum chamber is divided into eight sections, that is, four magnet chambers, two RF resonator chambers and two valley chambers.

A pressure inside the chambers must be kept as low as possible in order to reduce beam loss due to ion scattering by residual gas molecules. The total pumping speed of 12×10^4 l/sec is required to achieve the pressure lower than 1×10^{-7} Torr. To guarantee this pumping speed, ten cryopumps with speed of 10,000 l/sec and four cryopanels with 5,000 l/sec will be equipped to the chamber (5). Furthermore, in order to reduce the gas load, electron-cyclotron-resonance (ECR) discharge-cleaning technique is to be applied to the magnet chambers.

The vacuum system will be controlled automatically through a sequencer and monitored on the graphic display at the control desk. All elements of the vacuum system are in fabrication.

Injection and Extraction Systems

Specifications of the beam injection transport system from RILAC to the ring cyclotron have been fixed. The system includes a beam buncher and a beam chopper as well as bending and focusing magnets and various diagnostic devices.

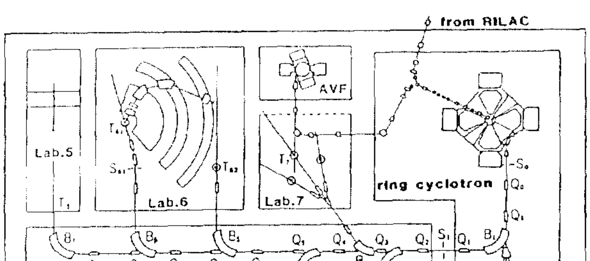
A beam sharing device will be installed just after the exit of RILAC to deliver the beam simultaneously to both a RILAC's experimental room and the ring cyclotron. In order to obtain a high quality beam, some injection conditions must be satisfied. The present system is so designed that this matching can be done. In designing the extraction system, realization of single turn extraction was taken into account (6).

Beam Handling System and Experimental Rooms

This ring cyclotron facility will be devoted to research works in various fields. Layout of the beam transport lines and the experimental rooms is shown in Fig. 6 and the main characteristics of the beam transport lines are listed in Table 3.

Sometimes it is beneficial for two experimental groups to share the beam. For that purpose, every 90° bending magnet is divided into two pieces, one of which deflects the beam by an angle of 25° and the other 65°. The dipole magnet which deflects the beam by an angle of 25° will be operated in a pulse mode and two users can share the beam.

Radio-active beam produced by nuclear reactions will be transported to the target station in Lab. 7 through a secondary-beam line (7).



⊗: Target Position ¦: Slit
B: Bending Magnet Q: Quadrupole Magnet

Fig. 6. Beam handling system and experimental rooms.

Table 3. Characteristics of beam on targets

Dispersive transport	
Energy resolution	0.01 %
Achromatic transport	
Energy resolution	0.02 %
Isochronous transport	
Time resolution	300 ps

Control and Beam Diagnostic Systems

A computer aided control system will be introduced for the ring cyclotron (8). The system is composed of a network of three computers and CAMAC system. The computer is MELCOM350-60/500 and its word length is 32 bits. One of them is used for control of the ring cyclotron, the second for control of the RILAC and the last will be used for program development and data base. These three computers are equivalent to each other and can be supported by each other through the network.

All the devices will be controlled through the CAMAC by the computer. To decrease necessary number of CAMAC crates, modules and signal cables, two types of interface modules named CIM (Communication Interface Module) and DIM (Device Interface Module) are developed using micro processors and memories. These intelligent interface modules can control the devices locally and ensure high speed sequential control and measurement without any aid of the control computer. The CIM can be linked with twelve DIM's. Informations between CIM and DIM are transmitted through Receiver/Transmitter integrated in the CIM and DIM and optical fiber.

We intend to optimize the operation of the ring cyclotron using the computer. In order to realize this successfully, it is necessary to equip enough number of beam diagnostic devices of various types measuring the current distribution, beam emittance and its phase relative to the RF voltage.

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