BEAM TRANSPORT SYSTEM FOR RIKEN RING CYCLOTRON

K. Hatanaka, T. Inamura, Y. Yano, A.Goto, M. Kase, and H. Kamitsubo
RIKEN, Wako-shi, Saitama 351-01, JAPAN

Summary

The beam transport system for the RIKEN ring cyclotron consists of lines from injectors to the cyclotron and those from the cyclotron to experimental halls. The beam transfer line from an injector (heavy-ion linac) and that to an experimental area were completed. One of the characteristic features of the line is beam sharing between the cyclotron and the linac experimental halls. For this purpose, a switching magnet is excited by pulsed current. Field mapping of dipole and quadrupole magnets was performed and the field distributions of all magnets were found as good as their specifications.

Introduction

The beam transport system for the RIKEN ring cyclotron consists of lines from injectors to the cyclotron and those from the cyclotron to experimental halls.[1] One of the injectors is the heavy-ion linac (RILAC)[2] which was completed in 1980, and the other an AVF cyclotron which will be constructed in two years. We have installed the beam transfer line from the RILAC and one beam channel to an experimental hall. The remaining lines will be constructed in two years. The beam transfer line from the RILAC is about 64 m long. The installed line to the experimental hall is a straight line with four quadrupole triplets. The vacuum pipe and the chambers for beam diagnostic devices are made of aluminum alloy. The pipe is 68 mm in outer diameter and the wall is 3 mm thick. The system is required to be held at pressure lower than $2\cdot10^{-7}$ torr. The aluminum vacuum system enables us to achieve the required performance with a small number of evacuating pumps. The beam diagnostic system is described in detail in a contribution to this conference.[3]

Field distributions of dipole and quadrupole magnets were measured in the midplane and were found as good as their specifications for all magnets.

An ion-optical calculation of the beam transfer line from the RILAC was performed on the basis of the following conditions: (1) maximum magnetic rigidity, $B\rho$, is 0.785 T·m for $^{238}U^{40+}$ at 0.84 MeV/u after passing through a charge stripper; (2) emittance in the transverse phase space is 6π mm·mrad at maximum; (3) energy resolution, $\Delta E/E$, is better than 0.15 % at FWHM; and (4) the RF phase width of the beam is less than 6°.

Description of the line from the RILAC

The beam transfer line consists of eight dipole magnets, fourteen quadrupole doublets, thirteen quadrupole singlets and thirteen steering magnets in both the horizontal and the vertical directions. Figure 1 shows the perspective view of the line. The beam from the RILAC passes the charge stripper (a thin carbon foil) and is deflected with a dipole magnet DAL0 by an angle

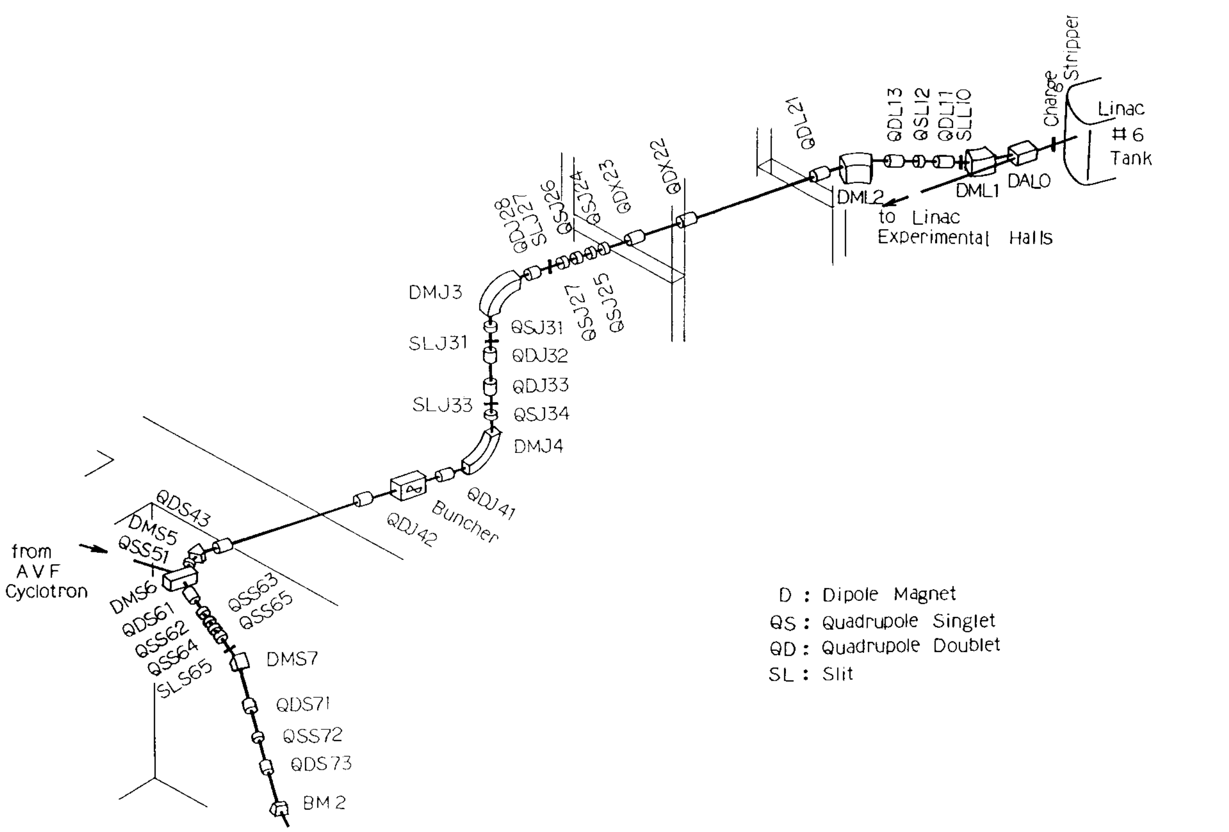

Fig. 1. Perspective view of the beam transfer line from the RILAC. The vertical distance between DMJ3 and DMJ4 is 7.8 m and that between DMS7 to BM2 is 4.0 m.

of 100 mrad. This magnet is made of laminations of 0.35 mm thickness and can be excited by pulsed current. It is possible to share the beam between the ring cyclotron and the RILAC experimental halls.

The spatial dispersion at the slit SLL10 after the magnet DML1 is calculated to be 0.46 m. In taking account of the beam size at this position, the momentum resolving power is about 20 and a single charge state is selected with the slit for light ions. The system from DAL0 to DML2 is a beam shifting section where the achromatic beam from the RILAC is again achromatic at the exit of DML2. Four quadrupole singlets QSJ24 - QSJ27 are introduced to obtain the erect ellipses at SLJ27 in the transverse phase space. The slit position SLJ27 is the object point for the succeeding momentum analyzing system from QDJ28 to QSJ31. The slit SLJ31 is located in the focal plane of the system, where the spatial dispersion is calculated to be 2.5 m and the angular dispersion is set to be zero by the quadrupole singlet QSJ31. With the slit, it is possible to limit the relative momentum spread less than 10^{-3} in full width. The section from SLJ31 to SLJ33 forms a doubly telescopic system consisting of two quadrupole doublets with the negative unity magnifications, and has the translational symmetry. The whole system from DMJ3 to DMJ4, therefore, dose not have an anti-mirror symmetry, but is an achromatic system.

A beam buncher is located between quadrupole doublets QDJ41 and QDJ42, and works in the second harmonic mode with respect to the frequency of the RILAC/ring cyclotron rf system (20-45 MHz).[4] The buncher reduces the pulse width of a beam, for example, from ±6° in rf phase at the exit of the RILAC to ±3.6° at the injection point of the ring cyclotron. The dipole magnet DMS6 is the junction of the line from the RILAC and that from an injector AVF cyclotron. The section from QDS43 to QDS61 forms an achromatic system with a mirror symmetrical arrangement and acts as a doubly telescopic system which has unity and negative unity magnification on the horizontal and the vertical plane, respectively. Four quadrupole singlets QSS62 - QSS65 are used to match the phase-space ellipses of the beam with those of the eigen ellipsoid of the ring cyclotron at the entrance of the cyclotron. The dispersion matching is basically carried out by the beam injection system.[5] This section, therefore, only makes the transverse phase-space matching (beam shaping) of the achromatic beam. The section from DMS7 to BM2 achromatically shifts down the beam by 4 m. The system is not made to act as a doubly telescopic system because of limited space, but has an anti-mirror symmetry.

Magnets in the lines

Parameters for the dipole magnets are summarized in Table 1. Electrical parameters for the pulse magnet DAL0 is listed in Table 2. The end profiles and the cross sectional shapes of the pole were determined from the numerical calculation of a magnetic field with the computer program TRIM.[6] The magnetic field was measured in the midplane for all the dipole magnets except for DAL0 by means of a carriage of three hall probes driven by a step motor. Examples of the measured radial distributions of the magnetic field are shown in Fig. 2. The deviation of the field ΔB/B is less than $1\cdot 10^{-3}$ for DMS7 in the required region which is estimated to be less than 20 mm in full width from the ion-optical calculation; for other magnets the deviation is less than $2\cdot 10^{-4}$ in the much wider region. The deviation of the effective field length at different

Table 1. Parameters of the dipole magnets in the transfer line from the RILAC

Name of magnet	DAL0	DML1	DML2	DMJ3 & DMJ4	DMS5	DMS6	DMS7
Deflection angle (deg.)	5.73	20.0	20.73	90.0	40.0	40.0	45.0
Curvature radius (m)	3.0	1.0	1.0	0.8	0.6	0.6	0.46
Maximum field (T)	0.27	0.8	0.8	1.0	1.31	1.4	1.71
Pole gap (mm)	60.0	60.0	60.0	60.0	60.0	60.0	42.0
Size of hollow-conductor (mm)	□9−φ6	□6−φ4	□6−φ4	□9−φ6	□9−φ6	□9−φ6	□9−φ6
Total number of windings	8	80	256	132	168	168	140
Maximum excitation current (A)	1,700.0	600.0	200.0	450.0	450.0	450.0	500.0
Maximum voltage (V)	4.9	60.0	66.0	83.0	54.0	63.0	47.0

Table 2. Designed values of electrical characteristics of DAL0.

Resistance		
Coil	2.8 mΩ	
Cable	0.2 mΩ	
Inductance		
Coil	72 μH	
Cable	3 μH	
Power loss		
Coil	< 3.5 kW	AC mode
Cable	< 8.7 kW	AC mode
Coil	8.0 kW	DC mode
Cable	16.0 kW	DC mode
Rise time	2.5 ms < t < 5 ms	
Fall time	2.5 ms < t < 5 ms	

Table 3. Parameters of the quadrupole magnets.

Type	Q170	Q220	Q420
Aperture (mm)	70.0	70.0	70.0
Max. gradient (T/m)	15.0	15.0	15.0
Max. current (A)	260.0	260.0	260.0
Max. voltage (V)	15.5	18.0	28.0
Length (mm)	170.0	220.0	420.0
Effective length (mm)	200.0 ±0.3	249.7 ±0.5	450.7 ±0.5

excitations is less than 1 mm for all the magnets.

Quadrupole magnets are of three types. Their parameters are summarized in Table 3. Magnets of the type Q170 are used in the beam transfer line from the RILAC. A quadrupole triplet in the line to the experimental hall consists of two Q220 and one Q420 magnets. The pole width is 70 mm possessing a hyperbolic shape. The yoke has a square structure. In order to obtain the wide flat region of the effective length, the optimum end-cut shape was determined by referring the experimental results obtained at KEK and INS.[7] The field distributions in the midplane were measured for two magnets of each type at three exciting currents of 100, 200, and 260 A. The deviation of the effective length is less than 1 mm for all magnets and for all excitations within the radial region of ±30 mm. Azimuthal distributions of the field were measured at the center of the magnets and at the radius of 30 mm. The measured data were analyzed to obtain the strength of multipole components. Values of the multipole components relative to the quadrupole one are $7\cdot10^{-4}$, $2\cdot10^{-3}$ and $3\cdot10^{-4}$ for the 3rd, 5th and 7th multipoles, respectively.

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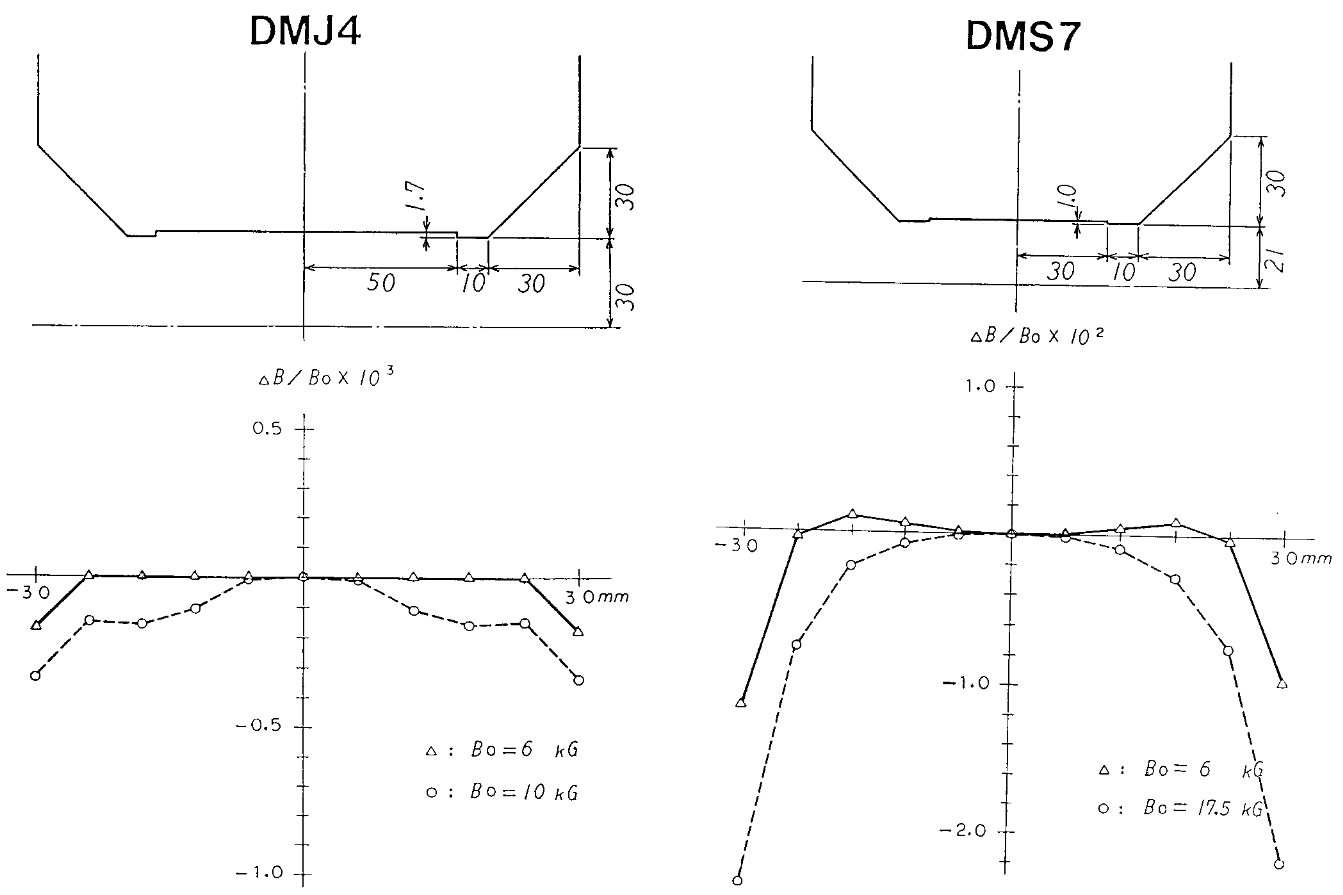

Fig. 2. Cross sectional view of the pole of dipole magnets and the radial distributions of the magnetic field.