INJECTION AND EXTRACTION SYSTEM OF THE RCNP RING CYCLOTRON

A. Ando, T. Itahashi, I. Miura and T. Nakatsuka

Research Center for Nuclear Physics, Osaka University
Mihogaoka, Ibaraki, Osaka 567, Japan

ABSTRACT

The brief survey of the injection and the extraction system of the RCNP Ring Cyclotron is described. The design principles for the magnets are also summarized. All the elements of this system were almost completed by Sumitomo Heavy Industries Ltd. in the financial year 1988. The precise measurements of the field quality of the elements and the effect on the main magnet are scheduled in this year, 1989.

INTRODUCTION

The scheme of the injection and extraction beam lines are shown in Fig.1. The beam from the AVF cyclotron, which is already selected in the momentum space and the emittances, enters in the new cyclotron vault at the point A. The triplet QI1 adjusts the transversal beam shape to confirm the emittances by measuring the beam profiles after passing through multiparallel slits in the region B. The triplet QI2 and the doublet QI3 make the shape of phase space of the injected beam to match the eigen ellipses of the Ring Cyclotron. The dispersion matching is mainly obtained by the entrance and exit face angles of the dipole magnets, and is finely adjusted by the additional quadrupole QM.

The extracted beam is distributed to one of the beam lines (T0,WN and WS) by the switching magnet SW1. At the region C, the double achromaticity is obtained by the doublet QM1, and the beam profile is so tuned by the triplet QM2 that there will be no problems in the downstream beam transfer.

The main parameters of these elements are given in Table 1 ~ Table 4. Table 5 shows the typical parameters of the electric and magnetic channels for the 400 MeV proton and α beams. In this calculation, the proton orbit is taken as the reference and the α orbit is optimized by minimizing the differences in the magnetic channels. (The differences are 2.6 mm in the EIC1 and EIC2, and are less than 1 mm in the orthers.)

Table 1 Dipole magnet

		BI1	BI2	BI3	BI4	BE	BM1
Max. field	kGauss	15.5	15.5	18	18	16	14.7
Radius of curveture	m	0.875	0.875	0.75	0.75	2.019	2.2
Bending angle	deg.	9.5	37.5	110	60	40	40
Entrance angle	deg.	4.75	0	19	-15	20	20
Exit angle	deg.	4.75	0	7	4	20	20
Gap height	mm	40	40	40	34	35	50
Pole width	mm	170	170	160	100	110	250
Pole shim							
thicknes	mm	-	-	1	0.5	1	-
position	mm	-	-	40	29.5	23	-
Radial cut of pole	C	25	25	30	10	22.5	15

Table 2 Quadrupole magnet

		QI	QM	QE
Max. field	T/m	10	2	20
Bore radius	mm	35	30	35
Core length	mm	400	105	400

Table 3 Magnetic channel

		MIC1	MIC2	MEC1	MEC2
Max. field	kGauss	3[a)]	0.5[a)]	0.9[a)]	10
Radius of curveture	m	0.698	0.752	1.906	0.277[b)]
Bending angle	deg.	~44	~42.5	~30.7	
Aperture					
width	mm	35	36	34	31
height	mm	32	22	26	16

a) variation from the field of the main secter magnet
b) length of the straight core

MAGNET DESIGN

Injection

The necessary aperture and the field tolerance are determined by the following considerations.

The typical optics are shown in Fig.2, where the effects of the electric and magnetic channels are neglected. The emittance of 10 π mm-mrad can be accepted and the aperture of the magnets should be larger than the beam size by 20 mm. When the optics is perfectly adjusted to match the Ring Cyclotron, unexpected kicks due to magnetic error fields causes the emittance dilution which results in the emittance increase, $\Delta\varepsilon = \beta\theta^2$, ($\beta$ and θ are the averages of the beta and an error kick in each magnetic element). In a dipole magnet with a bending angle θ_b, $\theta = \theta_b(\Delta B/B)$, and in a quadrupole magnet with a strength $K(= B'l/B\rho)$, $\theta = d(\Delta B'/B')K$ where d is the maximum excursion from the magnet center. If we take $\Delta\varepsilon = r\varepsilon_0$ and $d = \sqrt{\beta\varepsilon_0} + 10$ (mm) (magnet aperture), we obrain,

$$|\Delta B/B| < (r\,\varepsilon_0/\beta)^{1/2}/\theta_b,$$

$$|\Delta B'/B'| < K^{-1}(r\varepsilon_0/\beta d)^{1/2} \simeq r^{1/2}(K\beta)^{-1}.$$

Numerical examples for $r = 0.1$ and $\varepsilon_0 = 10$ mm-mrad are,

Dipole $|\Delta B/B| < (1.4 \sim 0.82) \times 10^{-3}/\theta_b$, where $\beta_x = 0.5 \sim 1.5m, and,$

Quadrupole $|\Delta B'/B'| < (3.2 \sim 0.53) \times 10^{-2}$, where $\beta = 10 \sim 30m$ and $|K| = 1 \sim 2m^{-1}$.

Extraction

The maximum vertical emittance of the 400 MeV proton beam is estimated as 7π mm-mrad supposing the increase by two times in the injection mismatch and the adiabatic damping by one third through acceleration. The horizontal emittance is determined by the orbit seperation at the EEC1, and estimated as 1.5π mm-mrad because of the 4 mm seperation and $\beta_x \simeq 2.7m$. The necessary aperture is determined from the same calculation as in the injection, in order that the transport line can accept the beam emittance of 10 π mm-mrad in both the horizontal and the vertical plane. The typical optics is shown in Fig.3, where the dispersion in the region D does not vanish because of the inappropriate

Table 4 Electric channel

		EIC1	EIC2	EEC1	EEC2
Max. field	kV	100	100	100	100
Gap	mm	10	10	10	10
Length	mm	340	320	409	548

Table 5 Parameters for 400 MeV beam

		Proton	α	(orbit difference) (mm)
Extraction	MeV	400.8	401.2	
Injection	MeV	63.6	86.3	
Rev. frequency	MHz	8.421	5.071	
MIC1	Gauss	1730	1889.3	-0.2
MIC2	Gauss	550	551.1	0.5
EIC1 / EIC2	kV/cm	80	59.1	2.6~1.6
EEC1 / EEC2	kV/cm	70	38	-0.7
MEC1	Gauss	900	759.3	-0.7 ~-0.3
MEC2	kGauss	10	9.187	0.1

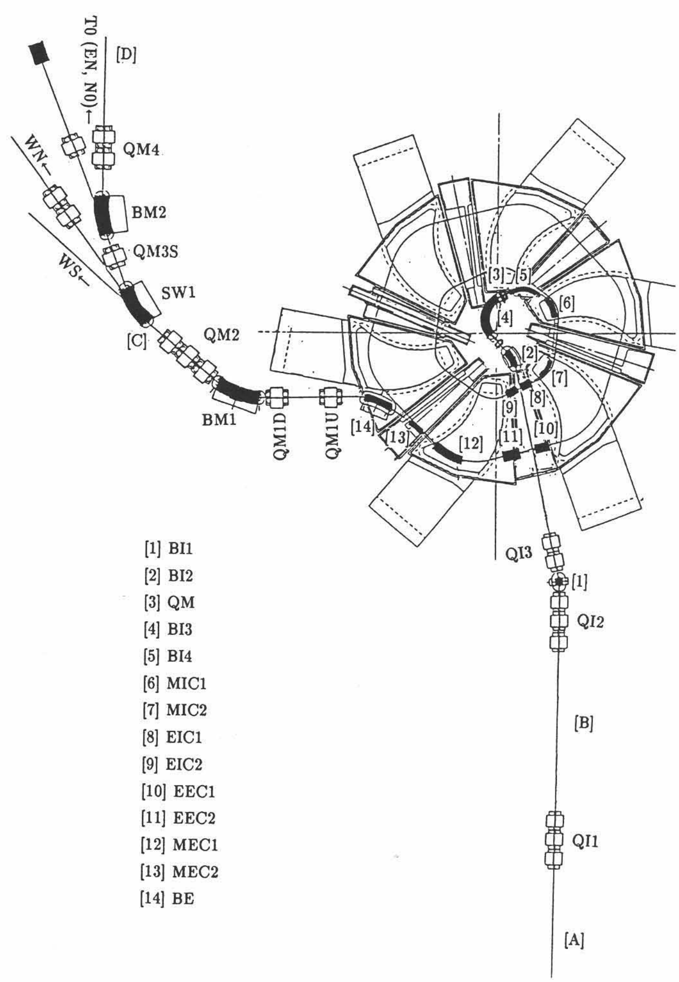

Fig.1 Scheme of injection and extraction

position of QM3S to keep the enough seperation for the beam lines of WN and T0.

At a target point, the ratio of the spread due to an unexpected kick (θ) to the designed spot is obtained as,

$$r = \Delta x/x_0 \le \sqrt{\beta/\varepsilon_0}\,\theta,$$

then for dipole magnets,

$$|\Delta B/B| < r\sqrt{\varepsilon_0/\beta}\,\theta_b^{-1} \simeq (1 \sim 0.5) \times 10^{-4},$$

for quadrupole magnets,

$$|\Delta B'/B'| < r\sqrt{\varepsilon_0/\beta}/(K\,d) \simeq r/(K\,\beta) \simeq 10^{-3},$$

where we take $r = 0.1$, $\theta_b \simeq .5\,mrad$, $K \simeq 3\,m^{-1}$ and $\beta \simeq 36\,m$.

MAGNETIC CHANNEL

The gap of the main secter magnets of the Ring Cyclotron is 60 mm. There are 35 trim coils on each pole face. The available height for MIC2 and MEC2 is 40 mm. Each of these two channels consists of a pair of the same winding coils, not to disturb the magnetic field for the circulating beam.

The cross section of MIC1 is shown in Fig.4. There are two iron sheets, of which the width is 80 mm and the thickness is 2.5 mm. The current can excite the magnetic field upto the strength of ~500 Gauss. The compensating coil is wound around the gap spacer for the main secter magnet.

MEC2 is a small conventional magnet with a verry high current density (~40 A/mm^2) and installed inside the accelerating elctrodes.

The position of each channel can be manually adjusted within ± 5 mm when the vacuum chambers are opened.

ELECTRIC CHANNEL

All the elctric channels have the same cross section shown in Fig.5. The maximum V^2/g is 10^4 kV^2/cm. The septum is a sheet of tantalum with the thickness of 0.5 mm. The elctrode is a block of copper which is

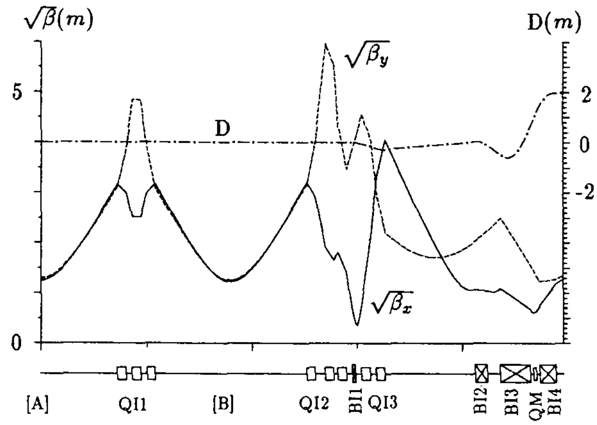

Fig.2 Typical optics of injection

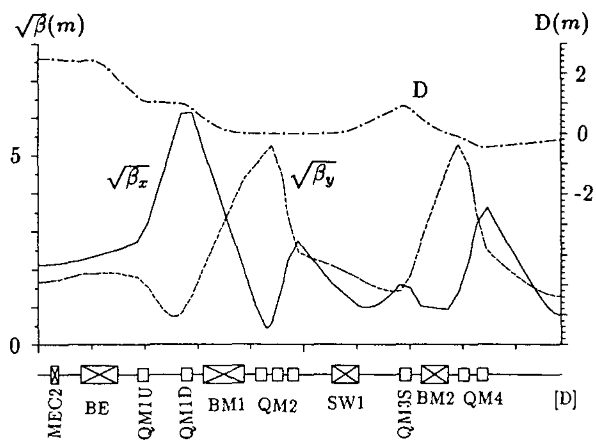

Fig.3 Typical optics of extraction

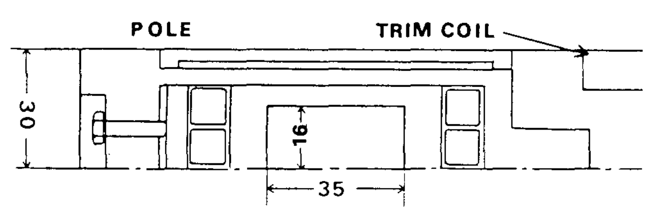

Fig.4 Half cross section of MIC1

cooled by water. Although the gap of each channel cannot be adjusted, but the location is precisely controled by moving both the entrance suport and the exit one. This is done by the remote control system and the adjustable ranges are ±10 mm.

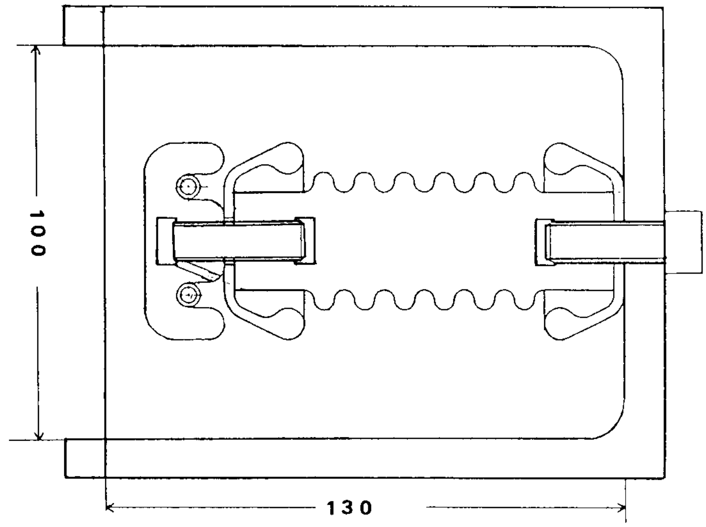

Fig.5 Cross section of electric channel

SPECIAL DIPOLE MAGNET

The dipole magnet BI4 has the maximum field of 18 kGauss and the orbit seperation from the circulating beam in the Ring Cyclotron is only ~170 mm. The material of Co-Fe (SME-V of Tokin Corporation, Sendai, Japan) is used for the poles in order to keep the aperture more than ±10 mm and to make the pole width less than 100 mm for the magnet gap of 34 mm. The cross section and the calculated field distribution are shown in Fig.6. The B-H curve of SME was measured for the sample ring and the result is given as follows.

outer diameter	47 mm
inner diameter	33 mm
thickness	5.5 mm

H(Oe)	B(Gauss)
0.5	310
1	777
2	2020
3	5130
5	13800
10	18300
20	20200
50	21600
65	21900
100	22200

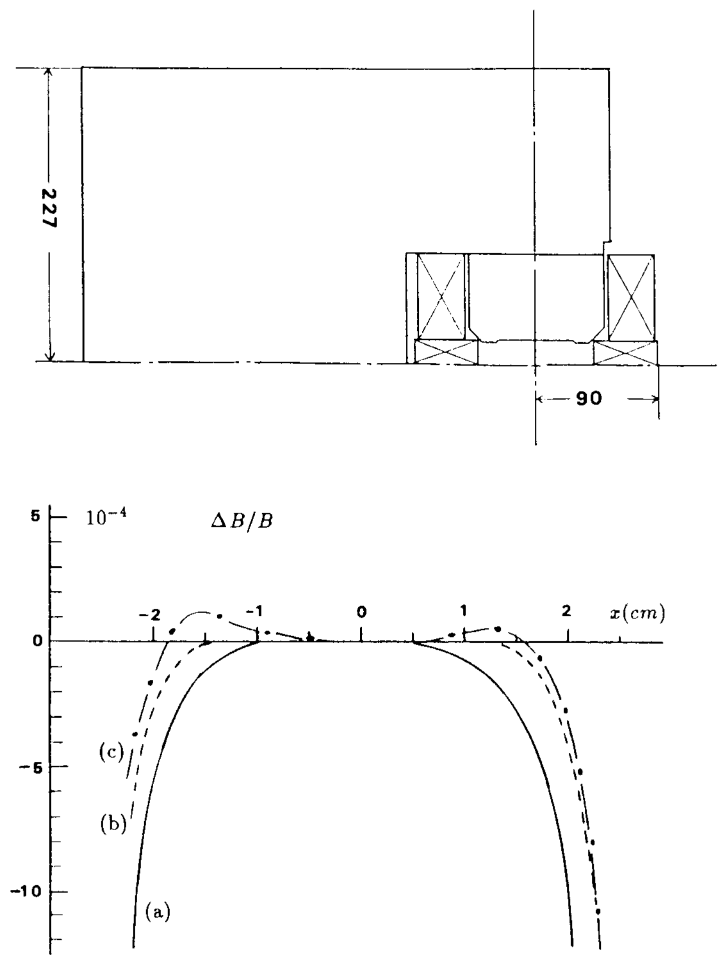

Fig.6 Half cross section and calculated field distribution of BI4
(a) 18kGuass, (b) 15kGauss and (c) $\mu = \infty$