BEAM TRANSPORT AND INJECTION SYSTEM AT TARN II AND TEST OF MULTITURN INJECTION

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ABSTRACT

Beam transport system from the INS-SF Cyclotron to the 'TARN II' Synchrotron Cooler Ring was designed and constructed. In the present paper, design conception and characteristics of the system as well as the experimental results of the multiturn beam injection are described.

INTRODUCTION

On the basis of the achievement of the accelerator 'TARN', the bigger scaled ring called 'TARN II' is constructed, aiming at the new development of accelerator technology and its utilization of the beam for experiment. The upgraded ring will be operated as an accumulatar, accelerator and cooler. The ring diameter is about 25 m and maximum energy is 1100 MeV for proton and 350 MeV/u for other light and heavy ions with charge to mass ratio 1/2. The detailed specification of the ring is described in the other paper in this conference.[1]

The SF Cyclotron is used as an injector for this ring. The whole system linked between the Cyclotron and the TARN II ring is shown in Fig. 1. From the Cyclotron to the entrance of the TARN II room, the configurations of all the optical elements and devices such as magnets, and slits etc. are not alterd.[2] In contrast, the transport line in the TARN II room are thoroughly changed, which matches the ring TARN II.

DESIGN OF BEAM TRANSPORT SYSTEM

The ultimate objective of the transport line is to obtain the good efficiency of the beam transmission and to match the optical condition of the beam injection into the main ring.

The design principles of this line are as follows.

(1) Beam is to be transported with the smallest loss.
(2) A doubly achromatic section is to be prepared for separating the optics of transport line up to the cave 2B after the SF Cyclotron from the injection parameters for TARN II operation modes.
(3) The Twiss parameters of the beam at the entrance of the ring is easily adjustable to match the condition of the different modes, which facilitates the multiturn injection.
(4) The beam size at the intersecting point with the TARN II ring is to be less than 15 mm in diameter.
(5) At the narrow gap of the inflector the exit of which is placed horizontally parallel to the closed orbit of the main ring, the dispersion function should be as small as possible.
(6) As the arrangement of magnets in the upstream section from the SF Cyclotron is not changed, the momentum analysing section is the same as before, but the parameters of several Q magnets after the BA4 magnet in the cave 2B are adjusted in accord with the change of optics in the downstream.
(7) In order to make the kicker magnet for beam pulsing system operate effectively, the horizontal beam width at the associated slit position should be reasonably small.

The beam injection line in the TARN II room is illustrated in Fig. 2, comprizing the following optical elements ; four window frame-type bending magnets[3] (BT1~ BT4), a C-type bending magnet (CM), four quadrupole singlets (QS1~ QS4), two quadrupole doublets (QDA,QDB), a quadrupole triplet (QTA,QTB,QTC), two pairs of steering magnets (ST1,ST2) and an electrostatic inflector (IF). Total length of the line from the exit of the SF Cyclotron to the entrance of the ring is 53.7 m.

The beam optics parameters are calculated using the program 'MAGIC'. The initial and final conditions for this calculation are summarized in Table 1. The initial conditions are the measured values of the emittance and the momentum spread of the beam extracted from the SF Cyclotron. The final conditions are so chosen that the beam matches to the injection condition corresponding to the TARN II operation modes. Three different modes are considered. As the SF Cyclotron can provide the beam of the maximum magnetic regidity of about 1200 kG· cm, that is regarded as the upper limit of characterizing beam momentum in the transport line. Among the different modes, one of the results in the calculation of the beam optics is shown in Fig. 3.

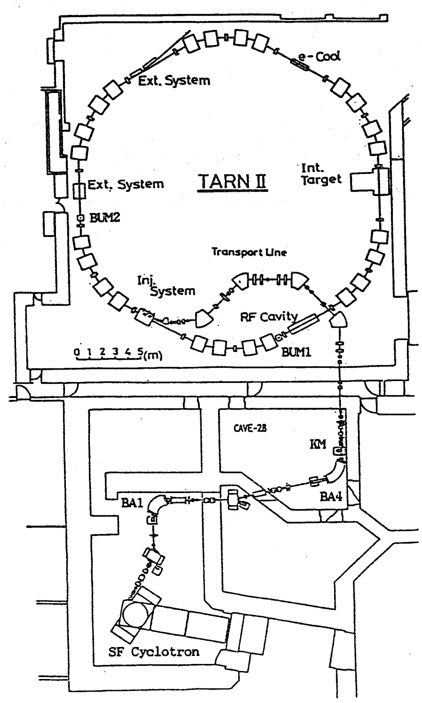

Fig. 1 Layout of SF Cyclotron and TARN II.

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Table 1 The initial and final conditions

1) initial conditions		
max. $B\rho$ (kG·cm)	1200	
momentim spread $\Delta P/P$	$\pm 7\times 10^{-4}$	
	Hori.	Verti.
90% emittance(mm·mrad)	15π	15π
Twiss parameters		
β (m)	1.176	0.385
α	−0.776	0.0
η (m)	0.73	0.0
η'	0.0	0.0

2) final conditions			
operation mode	Synch.	Synch.	Cooler
hori. tune ν_x	1.75	2.25	1.75
vert. tune ν_y	1.25	2.25	1.25
Twiss parameters			
β_x (m)	0.6	0.6	0.6
α_x	0.0	0.0	0.0
η_x (m)	0.0	0.0	0.0
η'_x	0.0	0.0	0.0
β_y (m)	7.35	3.27	3.60
α_y	−0.24	−0.82	−0.61

POWER SUPPLY AND ITS CONTROL

Each power supply for electromagnetic elements described above, is operated in two different ways. From the exit of the SF Cyclotron up to the first quadrupole magnets QDA along the transport line, all the power supplies and their control are operated in the control room of the SF Cyclotron. In contrast, the control of various elements in the TARN II room is operated in the newly allocated 'TARN II control room'.

All the power supplies for the optical elements in the TARN II room are operated by way of digital system. This is adopted because the long distance between the location of the power supplies and control room (80 m) gives advantage to transmission with digital signal than that with analog signal, considering the large noise caused by the radio frequency cavity or time-varying excitement of the magnets in the ring. The power supplies in the injection system are cotrolled and operated by use of the 16 bit microcomputer M16 and this is further linked to the minicomputer U400.

The CAMAC serial highway system is employed to regulate the power supply. The extended control boxes which are regulated with the CAMAC module, provide 10 channel digital-to-analog converters with either 12 or 16 bit resolution. To regulate these boxes and for further control and monitoring for each power supply, a 'process controller' of CAMAC module has been fabricated.

As a man-machine interface, a touch panel system is employed to regulate the control, where a rotary encorder system is used for smooth adjustment of setting parameters.[4]

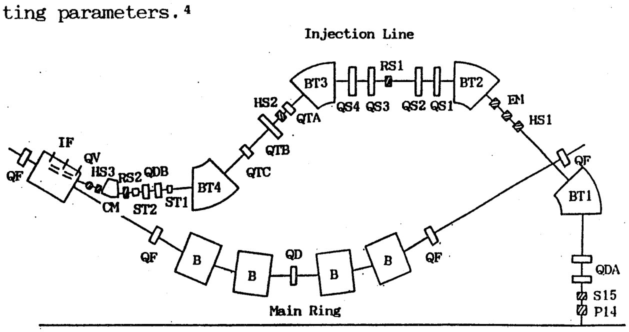


Fig. 2 Transport and injection line in the TARN II room. See the text for each element.

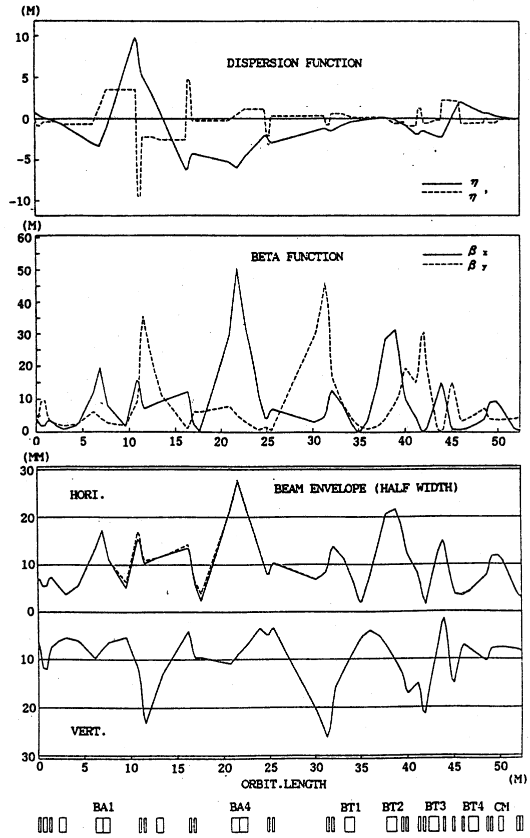


Fig. 3(a) Dispersion function η and its derivative η' and beta functions β_x, β_y.
(b) Beam envelopes (horizontal and vertical) along the transport line.

MONITORING DEVICES

At every section after each bending magnet, the beam monitor system is placed as shown in Fig. 2. Several different types of beam monitoring devices are used. In addition to the beam dump slit(S15) and profile monitor (P14), emittance monitor (EM), and horizontal slit stopper (HS), the newly fabricated monitors are the rod-stoppers (RSI and RS2) which enable to measure both the beam profile and current.

A quartz viewer is placed just before the gap of inflector to assure the final beam spot in the line.

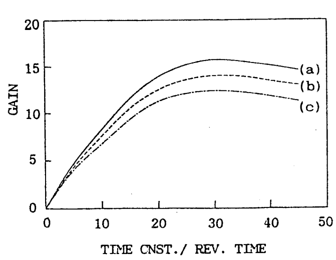


Fig. 4 Gain of multi-turn injection versus damping time constant of of bump field.
(a) $\Delta P/P = 0$
(b) $\Delta P/P = 0.1\%$
(c) $\Delta P/P = 0.2\%$

VACUUM SYSTEM

As there is a intersecting point with the ring at the middle of the transport line, the vacuum system of the new transport line is designed such that the duct and chambers can be bakable and powerful differential pumping system is provided. So far, 2×10^{-9} torr is obtained between magnet BT 2 and BT 3 even without baking. It is expected to reach much better vacuum by forthcoming baking procedure.

SCHEME OF THE MULTITURN INJECTION

In order to obtain higher beam intensity in the TARN II ring, the multiturn injection method is applied. It consists of the inflector which separates the transverse phase space in the injection beam line from the acceptance of the ring and two bump magnets which displace the closed orbit. For an efficient multiturn injection, a detailed simulation study has been performed.[5] The distance of the electrode which corresponds to the maximum beta oscillation amplitude at the injection point is set horizontally 70 mm apart from the central orbit. The two bump magnets (BUM 1, BUM 2) are positioned apart from each other at half of a wave length of horizontal beta oscillation as shown in Fig. 1.

The horizontal emittance of the injection beam is assumed 15π (mm · mrad) based on the measurements of the extracted beam from the SF Cyclotron and each parameter used for the calculation is listed in Table 2. The acceptance of the ring in the horizontal phase space is taken to be 300π (mm · mrad). The derivative of the horizontal beta function of the injection line is to be zero in order to fill a beam with horizontal phase space as much as possible. The vertical beta function and its derivative in the injection beam line are to be matched with those of the ring to avoid a beam dilution. On the other hand, the dispersion function and its derivative for the injection beam line are designed to be zero at the injection point in order to pass the beam through the gap of the inflector, while the dispersion function for the ring is 4.6 m in the same point.

On the assumption that the fields of bump magnets (maximum field 500G) are exponential dumping, a size and collapsing speed of the distorted closed orbit are optimizes in accord with the beta functions in the injection beam. The gain of multiturn injection in varying the dumping time constant are illustrated in Fig. 4.

The cyclotron beam is operated in continuous wave mode, whereas the ring can accept these bunches in very short period. Therefore, the beam pulsing system in the injection line is installed in the cave 2B, comprising a kicker magnet, two quadrupole magnets and two steering magnets. The magnetic field has roughly a rectangular waveform of 10μ sec in rise and fall time, 60μ sec in width of the flat top, and about 180 gauss at maximum in field strength.

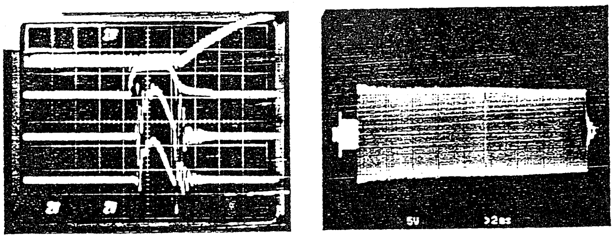
Table 2 Parameters used in the simulation.

1) Parameters of the injection beam

Emittance	ε_i	15π (mm · mrad)
Beta function	β_i	0.2m~ 0.7m
its derivative	α_i	0
Dispersion function	η_i	0
its derivative	η_i'	0
Momentum spread	$\Delta P/P$	0~ 0.2%

2) Parameters of the ring at injection point

Horizontal tune	ν_x	1.75
Beta function	β_x	9.06m
its derivative	α_x	-0.18
Dispersion function	η_x	4.55m
its derivative	η_x'	0
Acceptance	A_x	300π (mm · mrad)
Phase advance between two bump magnets	$\Delta\mu$	1.05π
Phase advance from bump 1 to injection point	$\delta\nu$	0.58π
septum thickness	t	0.5mm



(a) (b)

Fig. 5 (a) Timing relation of monitoring signals ; from above, the arc of the ion source in pulsed operation, discharge current of kicker magnet and those of bump magnet 1 and 2. Horizontal scale is 50μ sec/1div. (b) Signal from electrostatic monitor. horizontal scale is 2 msec/1 div.

PERFORMANCE ON BEAM TRANSPORT AND INJECTION

At the beginning of 1989, the first experiment of multiturn injection into the ring was carried out with the pulsed beam of 28 MeV α particles. At the exit of the SF Cyclotron, the beam emittance was measured at 15π mm · mrad (horizontal) and 20π mm · mrad (vertical), respectively and momentum spread was 0.2%. The one third of the beam was transported to the injection point of the TARN II. Since then, several times, multiturn injection were tried by using either 28 MeV α or 20 MeV proton beams. Usually pulse width and the repetition rate at the ion source were 3 msec and 30 Hz, respectively. The beam was multiturn injected into the ring with the excitation of two bump magnets. The decay time of bump fields was set to approximately 40μ sec which corresponds to about 20-30 times of revolution period of the beam in the ring. The frequency of RF field was set to be the value corresponding to the harmonic number 2 of the beam circulation (1.587 MHz in case of proton 20 MeV). In Fig. 5, the signal from the beam monitor is given together with monitoring signals of pulsed arc in the cyclotron, discharged currents of kicker magnet and those of two bump magnets. From the signal of the electrostatic monitor through the Intermediate Frequency (0.455 MHz) amplifier, the gain of intensity of the circulating beam can be seen to increase by about 14 turns, which realizes quite well the expected value of the simulation. The life time of the stored beam was measured in that case to be 12sec.

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