MULTITURN INJECTION AND RESONANCE CHARACTERISTICS OF TARN II

K. Noda, A. Noda, M. Kanazawa, T. Watanabe,
Y. Hattori and M. Yosizawa
Institute for Nuclear Study, University of Tokyo
Midori-cho 3-2-1, Tanashi-city
Tokyo 188, Japan

Abstract

A multiturn injection method is to be applied to TARN II in order to obtain high intensity beam. The maximum gain and efficiency are estimated at 15.5 and 33%, respectively. The beam intensity is expected at $\sim 10^9$ for proton.

The allocation of dipole magnets is determined on the basis of the field measurement so as to supress the closed orbit distortion. The maximum closed orbit distortion is estimated at 9 mm owing to the field error and the effective length error of dipole magnets. The stop band width of $3\nu_x$=5 excited by sextupole components of main magnets is also estimated at 8×10^{-4} in the Cooler Ring Mode (ν_x=1.75, ν_y=1.25).

Introduction

A heavy ion synchrotron-cooler ring TARN II is under construction at Institute for Nuclear Study, University of Tokyo (INS) on the basis of the study of TARN I[1] for the purpose of nuclear physics, atomic physics and other applications such as medical use.

TARN II is designed to accelerate protons up to 1400 MeV and heavy ions with charge to mass ratio of 1/2 up to 500 MeV/u (Synchrotron Mode)and to cool down their emittance and momentum spread by using a stochastic and an electron cooling(Cooler Ring Mode). Combination of an electron cooling and a microparticle internal target, which have been developed at INS, will realize a high resolution and a high luminosity experiment in an intermediate energy region.

The peak beam intensity of the SF Cyclotron[2] with K number of 67 which is used as the injector of TARN II is less than that of linac although the intensity of high charge state heavy ions of the SF Cyclotron will be improved by using ECR Ion Source in the near future. Therefore, a multiturn injection method[3] is to be applied to TARN II in order to obtain high beam intensity and to realize a high luminosity experiment. The behavior of an injected beam in this method is simulated so as to optimize the gain and the efficiency of the multiturn injection.

On the other hand, for a stable acceleration, cooling and extraction as well as a stable injection, dipole magnets are allocated so as to suppress a closed orbit distortion due to some deviation of the effective length and the field strength of each magnet according to the field measurement of main magnets in TARN II.

Furthermore, for suppressing a stop band width of a resonance line, the allocation of the quadrupole magnets is determined so that their sextupole components compensate these of the dipole magnets in the complex plane of the excitation coefficient along the Guignard's description of the resonance.[4]

Multiturn Injection

A multiturn injection system of TARN II consists of an electrostatic inflector which separates the transverse phase space in an injection beam line from an acceptance of the ring and two bump magnets which distort the closed orbit in the ring as shown in Fig.1.

For an efficient multiturn injection, the parameters such as a size and a collapsing speed of the distorted closed orbit and beta functions for the injection beam line in the injection point are to be optimized. Therefore, the computer simulations were performed.

The emittance of the injection beam and the acceptance of the ring in the horizontal plane are assumed at 15π (mm·mrad) according to the measurements and 300π (mm·mrad), respectively. Parameters used in this simulation are summarized in Table 1.

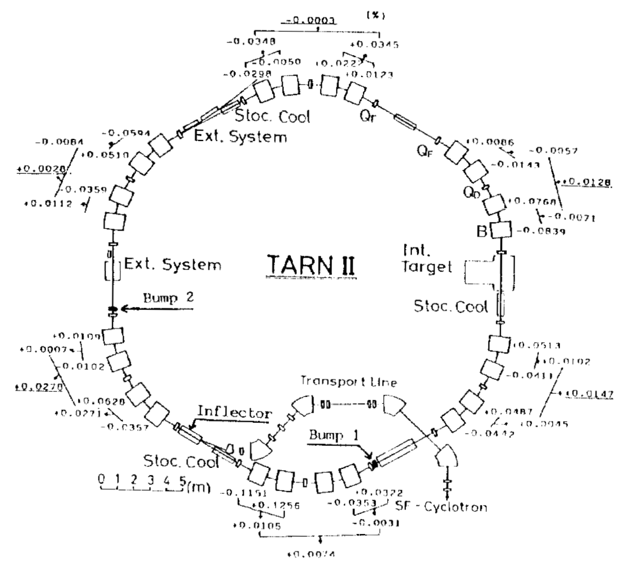

Fig. 1 Layout of TARN II and its multiturn injection system. Each number in the figure represents the deviation of integrated field strength along the magnet axis of each magnet (%).

Table 1 Parameters used in this 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		
Betatron wave number	ν_x	1.75
Beta function	β_x	9.06m
its derivative	α_x	-0.18
Dispersion function	η_x	4.55
its derivative	η'_x	0
Acceptance	A_x	300π (mm·mrad)
Phase advance from two bump magnets	$\Delta\mu$	1.05π
Phase advance from bump1 to injection point	μ	0.58π
Septum thickness	t	0.5 mm

The vertical beta function and its derivative for the injection beam line are to be completely matched with that of the ring to avoid a beam dilution in the vertical phase space and the derivative of the horizontal beta function is to be zero in order to fill a beam with the horozontal phase space as possible. On the other hand, the dispersion function and its derivative for the injection beam line are designed to be zero in the injection point in order to pass the beam through the gap of the inflector which was designed and manufactured for TARN I, while the dispersion function for the ring is 4.6 m in the same point.

On the assumption that the fields of bump magnets are exponential damping, the damping time constant of the fields τ is optimized at 30 × (revolution time) as shown in Fig. 2 for β_i = 0.4 m~ 0.7 m and $\Delta P/P$=0~ 0.2 %. The maximum injection gain and efficiency are estimated at 15.5 and 33 %, respectively, on the condition of the horizontal beta function size of β_i = 0.4 m~ 0.7 m for the injection beam line. The results are shown in Fig. 3. The maximum injection gain and efficiency are kept constant for β_i = 0.4 m~ 0.7m. A injection gain and a partial capture efficiency versus number of injection are shown in Fig. 4 in condition of β_i = 0.5 m, $\Delta P/P$ = 0 and τ = 30 × (revolution time). The injected beams during 47 turns in the horizontal phase space is shown in Fig. 5 in condition that the intensity distribution of the injection beam is the Gaussian one with the emittance of 15π (mm·mrad) (90 % emittance) in the horizontal phase space and its momentum distribution is also the Gaussian one with FWHM of 0.2 %. The effect of the mismatched dispersion function of the injection beam with that of the ring is observed.

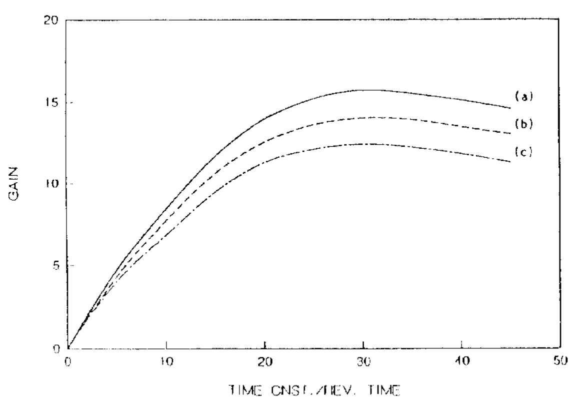

Fig. 2 Gain of multiturn injection versus damping time constant of bump field.
(a) $\Delta P/P$= 0 (b) $\Delta P/P$= 0.1 % (c) $\Delta P/P$= 0.2 %

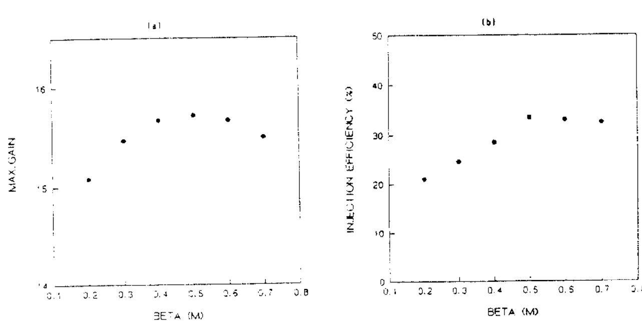

Fig. 3 (a) Maximum injection gain and (b) efficiency versus beta function for injection beam line.

Furthermore, the dependence of the injection gain on the acceptance of the ring is also simulated as shown in Fig. 6 since the acceptance is varied according to various operation modes of TARN II. Owing to the exponential damping of the bump field, the injection gain becomes saturate at the larger acceptance of the ring.

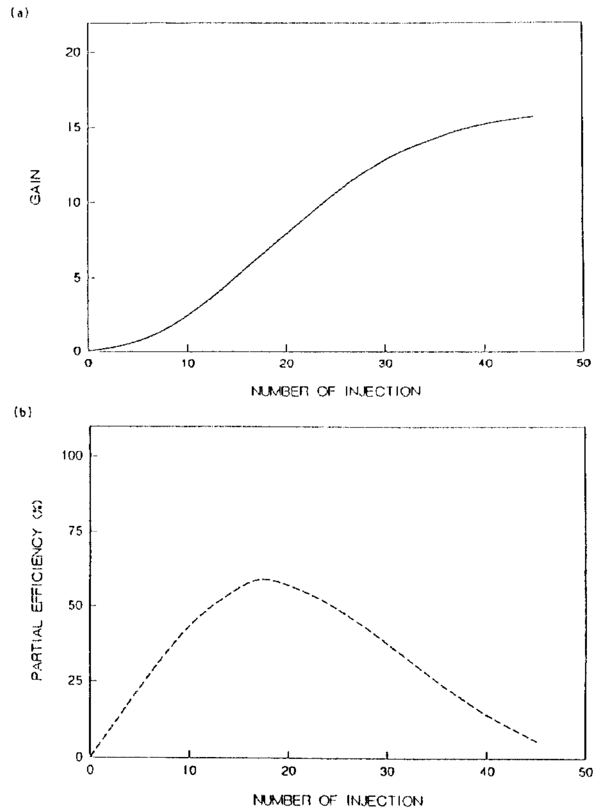

Fig. 4 (a) Injection gain and (b) partial capture efficiency versus number of injection.

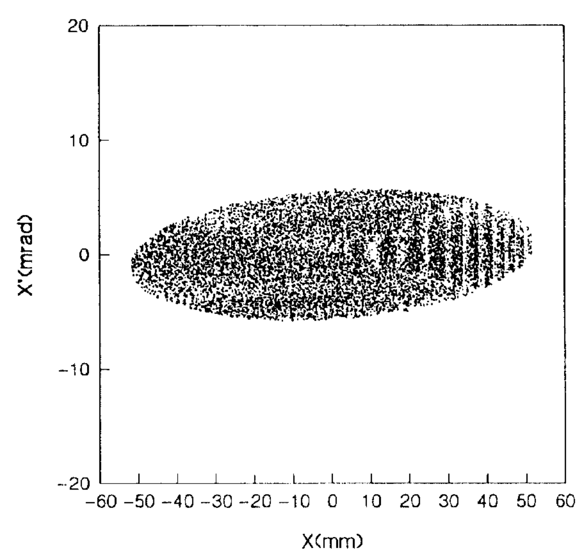

Fig. 5 The injection beams during 47 turns in the horizontal phase space.

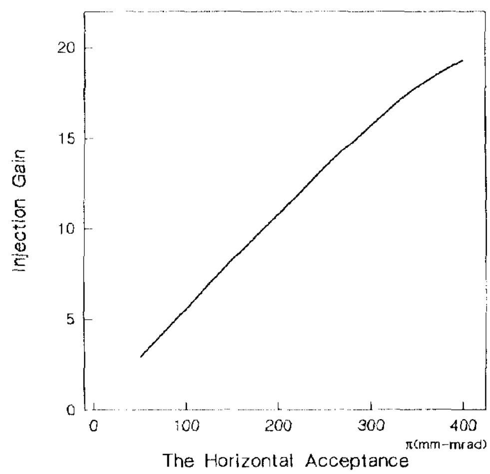

Fig. 6 The dependence of the injection gain on the horizontal acceptance.

Allocation of dipole magnets

According to the field measurement of main magnets in TARN II[5], a deviation of the effective length and the field strength of each dipole magnet Δ(BL)/BL was within$\pm 1.3\times10^{-3}$. Therefore, the closed orbit is to be distorted owing to these deviations. The maximum closed orbit distortion is estimated at 30 mm in a random allocation of dipole magnets by using statistical analysis.[6]

In order to suppress the colsed orbit distortion, dipole magnets are allocated so that the deviation of neighboring two dipole magnets is compensated by that of each magnet as shown in Fig. 1. Therefore, the summation of the deviation of neighboring two dipole magnets is supressed within$\pm 3.5\times10^{-4}$. As a consequence, the closed orbit distortion is reduced to 9 mm as shown in Fig. 7, which is numerically calculated and the acceptance is to be improved by using this method.

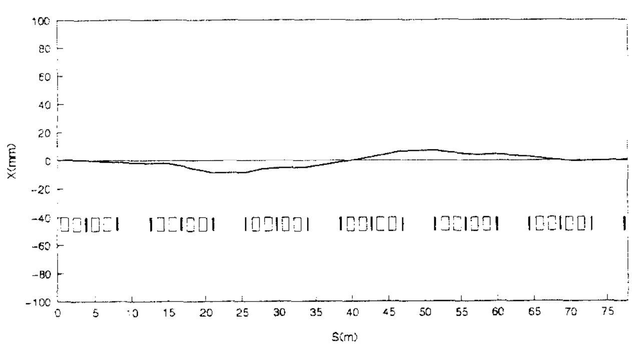

Fig. 7 The closed orbit distortion due to the field error and the effective length error.

Resonance characteristics

The stop band width of the $3\nu_x=5$ resonance line which neighbors with the operating point of TARN II is to be excited by some sextupole components of main magnets. The maximum sextupole component of dipole magnet was 0.3 m^{-2} at the field of 0.13 T according to the field measurement. In order to supress the stop band width as small as possible, the allocation of quadrupole magnets is determined so that sextupole components of dipole magnets is compensated with that of quadrupole magnets.

The excitation coefficient κ in the Coole Ring Mode (ν_x=1.75, ν_y=1.25) which has threefold symmetry is calculated for the third order resonance of $3\nu_x=5$ as shown in Fig. 8. Three dashed lines indicate excitation coefficients for focusing quadrupole 1, 2 and dipole magnets, respectively, while that for defocusing quadrupole magnets is negligible small and the solid line indicates the total excitation coefficient. On the assumption that the horizontal emittance is 200 π (mm·mrad), the stop band width of $3\nu_x=5$ is estimated at 8×10^{-4}.

Therefore, a stable acceleration and cooling as well as a stable injection is considered to be possible based on the fact that the stop band width of $3\nu_x=7$ in TARN I was mesured at 4×10^{-3}.[7]

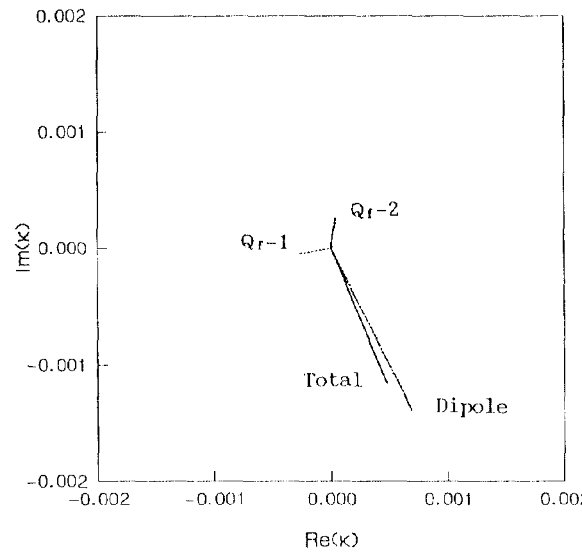

Fig. 8 The excitation coefficient in the Cooler Ring Mode.

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Calculations were performed by using FACOM M380R at the INS Computer Room.

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