Injection Method Using the Third Order Resonance at TARN II

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Abstract

The beam was successfully stored in the TARN II ring by an injection method using the third order resonance. Beam intensity obtained by the resonance injection is comparable with that by the multiturn injection. A new stacking method utilizing the resonance injection and the electron cooling is introduced.

I. INTRODUCTION

We studied an injection method utilizing the third order resonance. Resonance injection using the second order resonance was already performed in the electron ring[1]. We tried to apply the injection method utilizing the half-integer resonance to the ion ring. This injection mechanism is a reverse process of the slow extraction utilizing the third order resonance (in TARN II ring, the study of the slow extraction using the third order resonance was already done two years ago[2]). When the horizontal betatron tune is set near the third order resonance line, the beam from a transport line can be injected in the ring by a turn separation made by a sextupole field. The injection efficiency depends on the septum thickness of the inflector and the turn separation. The injected beam is stably stored in the ring by enlargement of the separatrix due to change of the horizontal betatron tune. Schematic drawing of this injection mechanism is shown in Fig.1. The resonance injection method is useful for the ring where the compact size is reqiured, because this method does not need the fast-bump magnets.

On the basis of the resonance injection scheme, beam simulations were performed using the TARN II lattice. This result is described in section II. Beam tests using the resonance injection were performed at the TARN II ring. Beam was successfully injected in the ring. The injection procedure and results are described in section III. Finally, a new idea of the resonance injection utilizing an electron cooling is introduced in section IV.

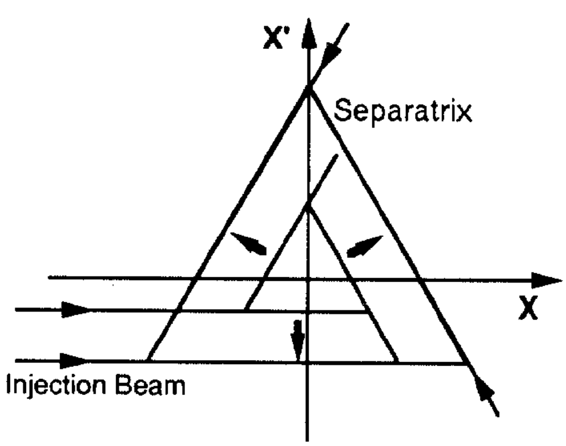

Fig.1 Schematic drawing of the injection mechanism utilizing the third order resonance.

II. BEAM SIMULATION

Beam simulation was performed to investigate the characteristics of the resonance injection. The tracking method with first order transfer matrices was used to calculate the beam behavior. Figure 2 shows the horizontal phase space at the injection point obtained by a single particle tracking. In the tracking, the unperturbed betatron tune was increased by about 2×10^{-6} per turn by changing the strength of the focusing quadrupole field. The sextupole strength $B''L/B\rho$ $(1/m^2)$ is set to 0.3015, which is the same as that used in the

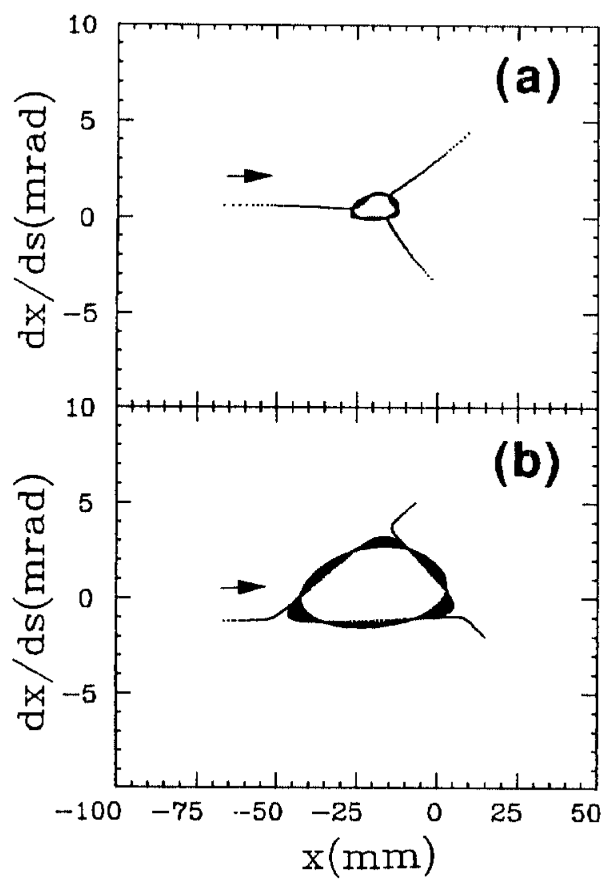

Fig.2 Phase space plot obtained a single particle tracking.

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slow extraction study[2]. The starting point of the unperturbed betatron tune in (a) and (b) is 1.6650 and 1.6674, respectively. After 5000 turns, the particles shown in (a) and (b) are stably stored in the phase space corresponding to about 10π mm•mrad and 50π mm•mrad, respectively.

Figure 3 shows the phase space obtained by the muti-particle tracking calculation. (a) is the horizontal phase space at the injection point. Dots show particles stored in the ring. Solid line indicates injection beam emittance of 15π mm•mrad (design value). (b) is the phase space plot of the stored particles at a certain place in the ring. (a) shows that the acceptance to store particles in the ring can be covered with the emittance of the injection beam (in other words, injection efficiency is low). If the peak intensity of the beam from the transport line is equal, beam intensity stored by the resonance injection is the same as that by the multiturn injection.

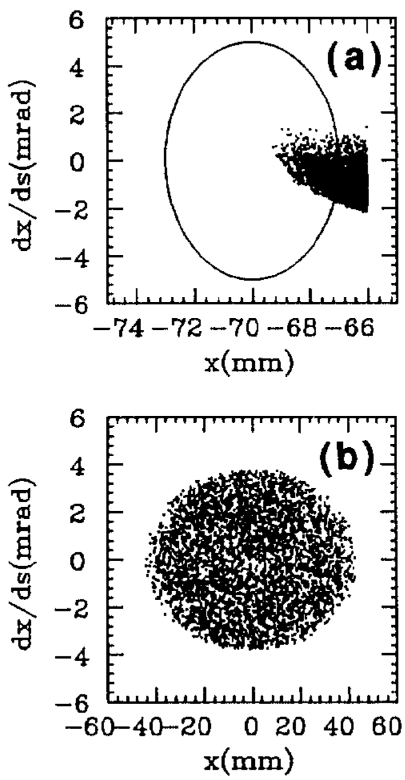

Fig.3 Phase space plot obtained multi-particle tracking.

III. BEAM TESTS

a) Procedure

The injection equipment consists of an electrostatic inflector, a sextupole magnet, and three correction coils of the lattice dipole magnets. Layout of the injection equipment in the TARN II is shown in Fig. 4. The same inflector as used in the multiturn injection was also used in the resonance injection. The sextupole magnet is placed at the same position as placed in the slow extraction. The beam tests were carried out with protons at the energy of 20 MeV from the SF cyclotron. The injection procedure is as follows.

1) The sextupole magnet is operated with dc operation. The horizontal betatron tune is shifted from 1.654 to 1.691 by increasing the strength of the field gradient of the radially focusing quadrupole magnets in the lattice.

2) At the beginning of the beam injection, the orbit bump-coils are excited in order to obtain the minimum beam aperture at the inflector. A bump of about 20 mm from the orbit center was made at the position where the inflector is placed.

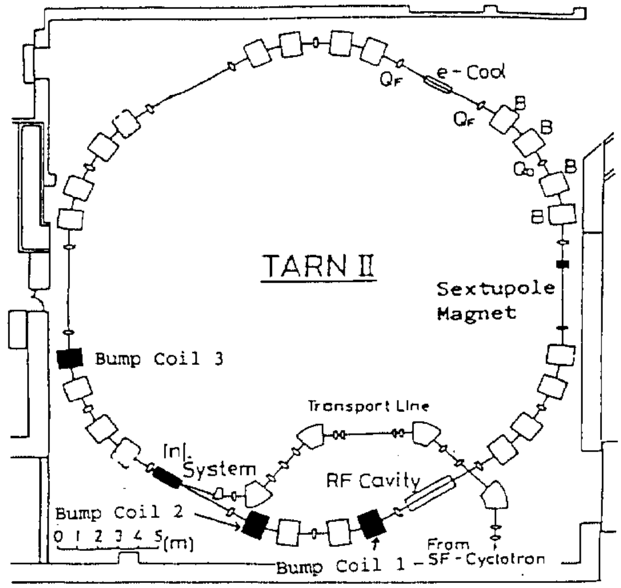

Fig.4 Layout of the resonance injection system of TARN II.

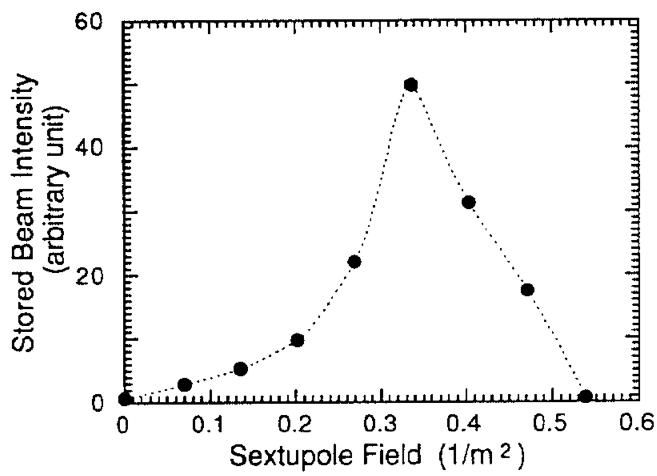

Fig.5 Dependence of the stored beam intensity on the sextupole field.

The pulse width of injection beam is set to about 500 msec with the repetition rate of about 0.2Hz. This width is rather longer than that with the multiturn method, which is determined by limit of the ramping rate of the power supplies of the lattice quadrupole magnets. All of the injection equipment was remotely controlled with a system using a CAMAC interface and a DAC board connected to a personal computer.

b) Results

Figure 5 shows stored beam intensity measured as a function of the sextupole strength. The intensity has a maximum around B"L/Bρ=0.33. This reason is qualitatively interpreted as follows; the un-captured area in the phase space of the ring increases with the decrease of the sextupole strength. This decreases the stored beam intensity. On the other hand, when the sextupole field is too strong, the turn separation become too large. This decreases the injected beam intensity.

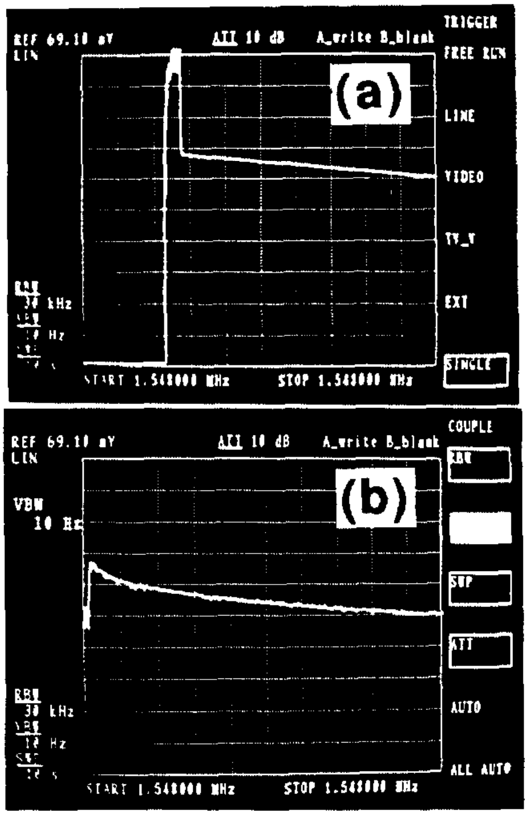

Fig.6 Stored beam intensity measured by the electrostatic monitor. (a) and (b) are by the resonance injection and the multiturn injection, respectively.

Next we measured the dependence of the stored intensity on the ramping rate of the betatron tune. This result shows that the stored intensity does not depend on the tune ramping rate in the range from 0.04/sec to 0.19/sec. Finally, beam intensity stored by the resonance injection was compared with that by the multiturn injection. Figures 6 (a) and (b) show beam intensity stored by the resonance and the multiturn injection, respectively. Beam intensity was measured by the electrostatic monitor. The obtained beam intensity for the resonance injection is comparable with that of the multiturn injection. The stored intensity amounted to about 6 μA corresponding to the multiplication factor of about 10, where the multiplication factor is defined as the ratio of the stored to the injected intensity. This multiplication factor is expected to be increased by optimization of the inflector position.

IV. PROPOSAL OF COOLED STACKING USING RESONANCE INJECTION

There is a stable region in the horizontal phase space for the third order resonance. Area of this stable region is determined by strength of the sextupole field. If the captured beam in the ring is compressed in this stable region, the beam is kept in the stable region by the resonance crossing again (see Fig.7). An electron cooling is available to compress the beam emittance. For example, in the case of TARN II, injected proton beam is compressed up to less than 1π mm•mrad with typical cooling time of several seconds[3]. Therefore, the cooled stacking utilizing the resonance injection is possible by repeating the resonance crossing, just like that with the multiturn injection[4]. The stacked beam intensity depends on the beam life time. Therefore, the repetition rate of the stacking and the sextupole strength need to be adjusted so as to obtain the maximum intensity.

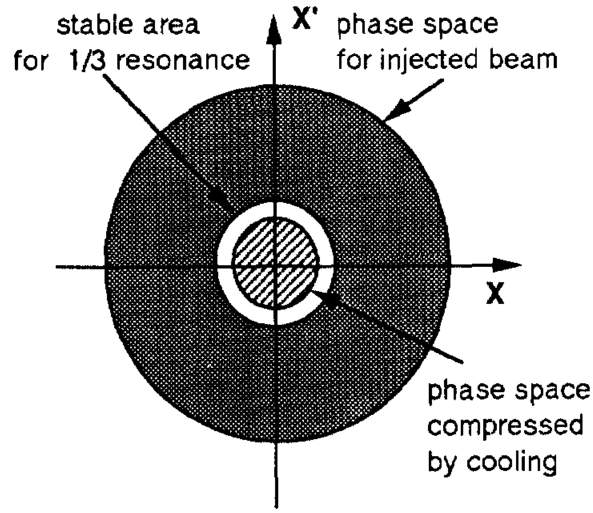

Fig.7 Schematic drawing of the cooled stacking mechanism utilizing the resonance injection.

V. ACKNOWLEDGEMENT

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VI. REFERENCES

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