MEASUREMENTS ON INJECTION PROPERTY IN HIMAC SYNCHROTRON

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Abstract

A multiturn-injection method has been used in HIMAC synchrotron to obtain higher beam-intensity. A total and a partial efficiency of the multiturn injection are measured. The stored beam-intensity and its life-time were considerably decreased above 600 μA of an injection current of alpha ions with 6 MeV/n of the energy, mainly due to the space charge effect on the transverse tune. A dependence of a stored intensity on a vertical tune is investigated, and the tune-shift by the space charge effect is measured.

1 INTRODUCTION

HIMAC (Heavy Ion Medical Accelerator in Chiba) is an accelerator complex dedicated to medical application [1]. Clinical trials have been successfully progressing since June 1994 [2] and the treatments of 230 patients were completed by February 1997.

Heavy ion beams are very suitable for cancer treatment because of its high dose localization and high LET characterisitic. A high irradiation-accuacy has been required in the heavy ion therapy, however, because of the high dose-localization. Therefore, innovative works to realize a high accuarcy treatment are under way: (1) The irradiation gated by respiration of a patient was developed and has been used for a lung or a liver cancer moved along with a respiration [3]. An irradiation dose-rate in this case is maximized at DC beam with a sufficient intensity. (2) A secondary beam course is being constructed in order to treat a cancer around a critical organ by using positron emitter beam such as ^{11}C and ^{19}Ne that can be monitored and verified for dose localization by a positron camera [4]. When a patient is treated by the positron-emitter beams, an intensity of a primary beam is required naturally higher by two order than the treatment by the primary beam.

An extracted beam-intensity from HIMAC synchrotron should be increased by about one order in both cases, because HIMAC accelarater-complex can already deliver higher beam-intensity by about one order compared with the intensity in the present treatment.

In the commissioning stage of HIMAC synchrotron, however, a stored beam-intensity after an rf-capture was considerably decreased above 600μA of an injection current of He^{2+} with 6MeV/n. The space charge effect on transverse tune was suspected and horizontal tune-shift was observed. Therefore, an injection efficiency and a dependence of a stored intensity on a vertical tune are measured as further investigation. The paper reports the preliminary results.

2 MULTITURN INJECTION

A multiturn-injection system of HIMAC synchrotron consists of an electrostatic inflector which separates the horizontal phase-space in an injection beam line from an acceptance of the ring, and four bump magnets which distort the closed orbit. The design parameters of the multiturn injection are summarized in table 1. A septum of the inflector is located at the distance of 65mm from the central orbit in the ring. A collapsing speed of the bump orbit is 1.3mm/turn to obtain a gain of about 20 turn in injecting a beam of 50 turn in the design stage. An efficiency of the multiturn injection is expected at about 40%, because of a shadow of the septum with 0.5mm in thickness and mismatching a dispersion function of the injection beam with that in the injection point of the ring.

Table 1. Parameters in the multiturn injection

(a) Injection Beam Parameters	
Energy T (MeV/n)	6.0
Emittance ε_x (mm mrad)	13.2 π
Twiss parameters β_x (m)	0.33
α_x	0.0
Dispersion func. D_x (m)/ D'_x	0.0/0.0
Momentum spread $\Delta P/P$	0.3% (FWHM)
(b) Ring Parameters at Injection Point	
Hori. tune Q_x	3.75
Twiss parameters β_x (m)	6.59
α_x	1.32
Dispersion func. D_x (m)/ D'_x	2.06/-0.23
Septum thickness (mm)	0.5
Acceptance A_x (mm mrad)	264 π

The injection gain was estimated at about 15-20 turns in a commissioning stage, however, because the transverse emittance of an injection-beam from the injector linac was around 7π mm mrad which was reduced by 50% compared with the design one. Thus, the collapsing speed of the bump orbit is optimized to 0.87mm/turn. As a result, the injection gain is improved to about 30 turns and the stored beam-intensity just after the injection is increased by a factor of about 1.5.

A partial capture-efficiency of the multiturn injection in 1.3mm/turn in the collapsing speed of the bump orbit is also measured by using a chopped injection-beam. A time-width of a chopped beam is about 20μs corresponding to a time period of 4-5 turns in the ring. Figure 1 shows the measurement of partial-efficiency in a 70μA of an injection peak-current, ant also a survival rate after 1s of an rf-capture. The partial capture-efficiency is maximized at around 120μs corresponding to 30 turns of the injection beam in the ring, which is almost consistent with the design. The survival rate after 1s is decreased at later injection-timing, because of reduced a clearance between an acceptance of the ring and an amplitude of the betatron oscillation.

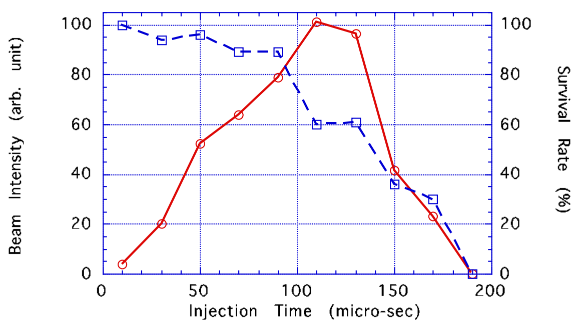

Fig. 1 A partial capture-efficiency just after the rf-capture and the survival rate after 1s. The solid and broken line indicate partial efficiency (arbitrary unit) and the survival rate (%), respectively.

3 SPACE CHARGE EFFECT

The total and the partial capture-intensity in the multiturn injection are almost proportional to the injection-intensity in increasing from 70 to 200μA of the injection peak-intensity. In increasing injection beam-intensity from 200 to 700μA in a peak-intensity, however, the stored intensity after the rf-capture with an adiabatic capture is not proportional to the increasing ratio. The stored intensity is improved by increasing the vertical tune by around 0.1 when the injection-intensity is increased from 200 to 700μA. These results suggest a limit of a stored beam-intensity by a space charge effect.

A dependence of a stored intensity on the vertical-tune is surveyed in the injection peak-intensity of around 100, 300 and 780μA, therefore, because the vertical tune-shift and -spread by the space charge effect are larger by factor of about 5 than the horizontal one in HIMAC synchrotron. The surveyed tune-line in the tune diagram is shown in fig. 2.

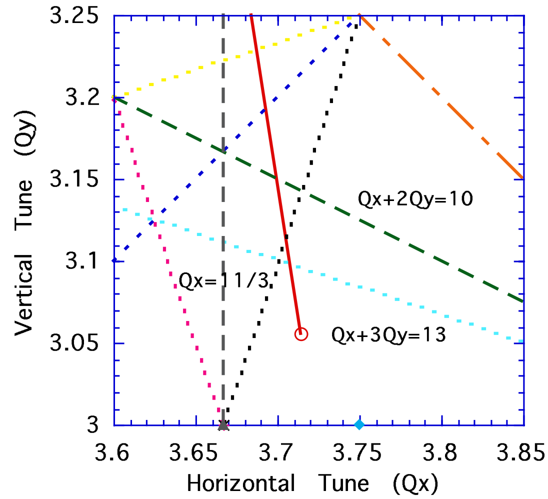

Fig. 2 The surveyed tune-line is indicated by the solid line. The dashed, broken and dotted line are 2nd, 3rd and 4th resonance line, respectively.

The measurement results are shown in fig. 3(a)-(c). These figures show a stored beam-intensity after 0.1s of the injection in setting various Qy while current of focusing quadrupole magnet is fixed to be 3. 689 of the Qx in 3.129 of the Qy. Other than the common fall off due to Qy=3 integer resonance, distinct dips are observed in both cases of rf-on and off. They are caused by the resonance of Qx+2Qy=10 in the cases of 100 and 300μA, while the dip in 780μA by Qx+3Qy=13. The vertical tune-shift depending on the stored beam-intensity is estimated at around $-0.05/10^{11}$(ppp) in a coasting beam, which is almost consistent with Laslett tune-shift. The tune-shift is obtained as follows; In a working point above Qx+2Qy=10 such as (3.685, 3.176), a stored beam is lost by two step in the case of 780μA, as shown in fig. 4. Such a beam-loss is caused by crossing two resonance lines which are Qx+3Qy=13 and Qx+2Qy=10. Tune-shift is gradually decreased by decreasing a stored beam-intensity after the tune-shift is quickly occurred during the multiturn injection period of 300μs. The tune-shift is obtained by calculating the distance along with the tune-shift line between two resonance lines and measuring a stored beam-intensity just before a beam-loss, therefore, in the assumption on a ratio of horizontal tune-shift to vertical one of 5-10 by the space charge effect.

A stored beam-intensity is rapidly decreased after the rf-on with an adiabatic capture, on the other hand, because the tune-shift and -spread is increased by bunching effect which leads a bunching factor to above 2 and vertical chromaticity of -6.0. The tune-shift in the rf-on is also measured by the same way in the coasting beam; Tune-shift is enlarged by factor of 2 compared with that in the coasting beam, which is consistent with a measurement result of the bunching factor.

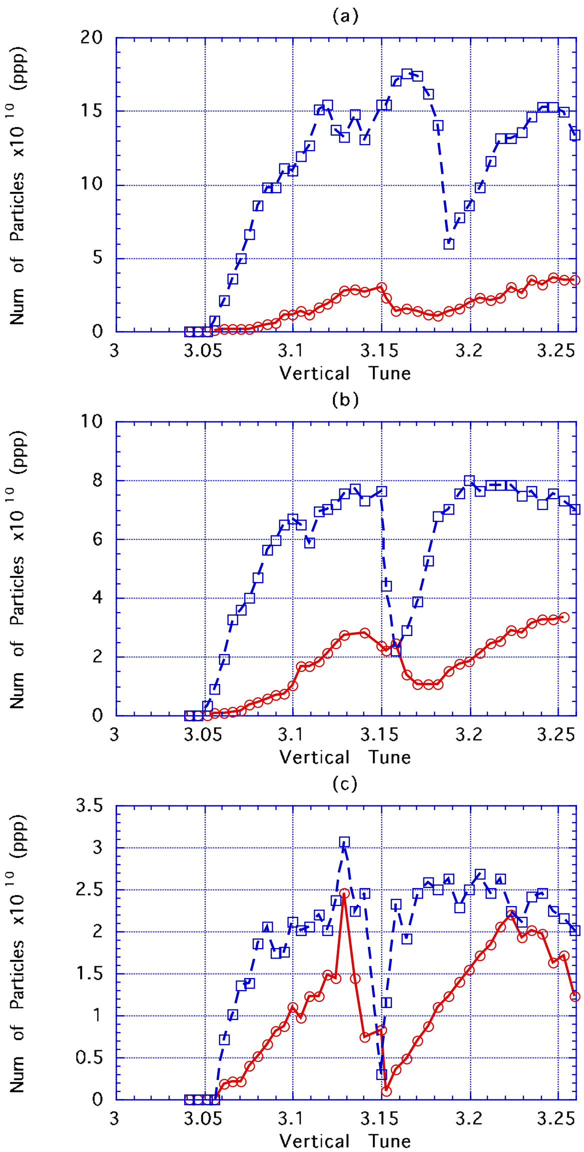

Fig. 3 The dependence of the stored intensity after 0.1s of the injection on the vertical tune. The injection peak current of (a) 780μA, (b) 300μA, and (c) 100μA. The broken and the solid lines indicate the coasting beam (rf-off) and the bunched (rf-on) beam case, respectively.

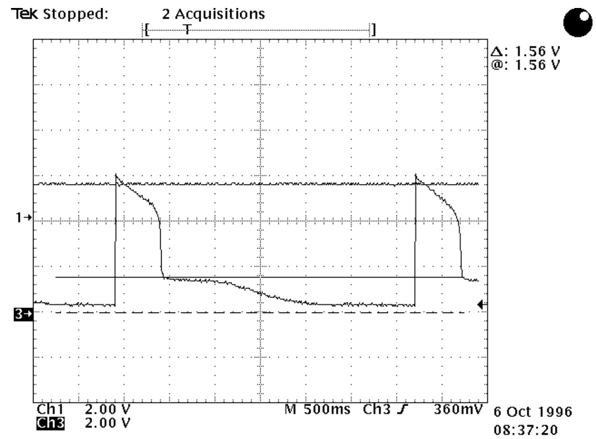

Fig. 4 The time-change of the stored beam-intensity in the injection current of 780μA when the rf is turned off. The working point is (3.685,3.176). The vertical scale corresponds to $6.0\mathrm{x}10^{10}$ppp/div and the horizontal scale is 500ms/div.

4 SUMMARY

Total efficiency of the multiturn injection is achieved at 45% in just after the multiturn injection. Partial one is maximized at around 30 turns which is basically consistent with the design.

A space charge effect on a transverse tune is investigated by a vertical-tune survey. The tune-shift in a coasting beam is obtained by measuring intensity just before beam loss in crossing two resonance lines and calculating the distance between them. The result is consistent with Laslett tune-shift. A stored beam-intensity is considerably decreased due to enlarged tune-shift and -spread by bunching effect.

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