CHARACTERISTICS OF INJECTED BEAM AT HIMAC SYNCHROTRON

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Abstract

At the HIMAC synchrotron, a multiturn-injection was optimized. The stored intensity was increased by the factor of around two. On the other hand, we have carried out the tune survey in order to obtain a long lifetime even in the high intensity that brings the space charge effect. We will describe the experimental result.

INTRODUCTION

The HIMAC (Heavy Ion Accelerator in Chiba) accelerator complex [1] has been operated since June 1994 to deliver carbon ions for cancer therapy and the total number of patient treated exceeds 2000. Based on the ten-years experience at HIMAC, a carbon-therapy accelerator facility is proposed for a spread wide use in Japan [2]. Such an accelerator should be downsized because of a cost reduction. Especially, a synchrotron ring is to be downsized by around half in a circumference compared with the HIMAC synchrotron. In this case, thus, the proposed synchrotron should increase the intensity by around twice compared with that of the HIMAC synchrotron, because of around half circumference. For the purpose, the multiturn injection method has been improved at the HIMAC synchrotron. The improvements for the multiturn injection were followings: (1) Determination of the horizontal tune and beta function from the result of simulation, (2) Changing twiss parameters at injection beam transport in order to match them with the ring. Consequently, the gain of the multiturn injection was increased by 50%, and the injection beam transport efficiency was improved by 15%. Tune survey was carried out in order to obtain a long lifetime even in the high intensity that brings the space charge effect. The experiment and simulation results are described in this paper.

OPTIMISATION AND EXPERIMNT FOR MULTITURN INJECTION

The Horizontal Tune and Beta Function

At first, the horizontal tune (Qx) and the horizontal beta function (βx) of the injection line was optimized through the simulation. As a result is shown in Fig. 1, the multiturn-injection gain was obtained as both the functions of the Qx and of the βx of the injection line at the injection point. It is noted that the simulation conditions are a collapsing speed of the bump orbit of 0.71 mm/turn, the momentum spread of ±0.1% and the injection-beam emittance of 10 π·mm·mrad. It is obviously found from Fig. 1 that the highest gain is obtained under Qx of 3.74 and the βx of around 0.75m.

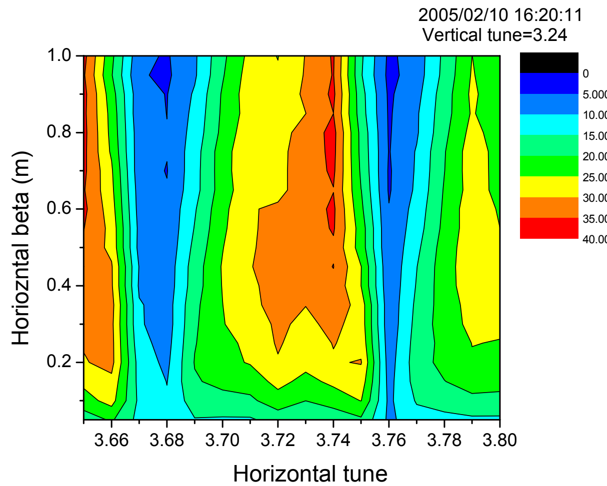

Figure 1: The multiturn-injection gain as both the functions of the horizontal tune and the horizontal beta function of the injection line at injection point.

Optimization of Beam Injection Line

Considering the optimum Qx and βx at injection point, the injection beam transport line was re-designed. In this re-design, we carried out not only to optimize twiss parameters at injection point, but also to suppress the large beta function in the injection line. Consequently, the transmission efficiency was increased to around 100% from 85% in the old optics. In the transport line, the calculated envelope was in good agreement with the measurement profiles. Furthermore, the vertical profile of the circulating beam after multiturn injection was measured by using non-destructive beam profile monitor [3]. As the measurement and simulation results are shown in Fig 2, it is clearly observed that the vertical twiss parameter in the injection line can match sufficiently with those of the ring.

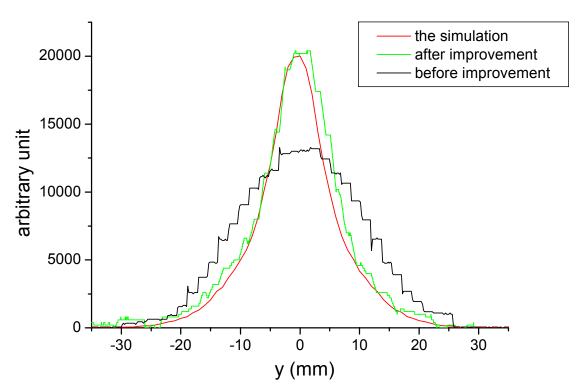

Figure 2: The vertical profile of the circulating beam. Black line is before the optimization and green line shows the beam profile with the new optics. Red line is beam distribution with the new optics by simulation.

Injection Gain and Intensity

The total injection gain after optimizations is compared with that before optimizations, as shown in Fig. 3. The total gain after optimizations was increased by around 50%, compared with that before optimizations. On the other hand, the transmission efficiency trough the beam-injection line was increased by 15%. As a result, the stored intensity after optimizations was increased to 8.2·1010 from 4.6·1010 ions before optimizations.

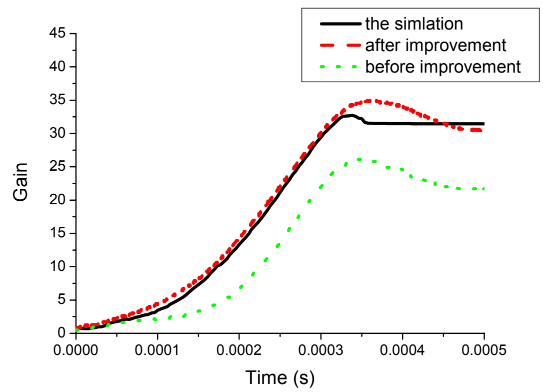

Figure 3: The injection gain during the multiturn injection and 500 μs after the end of the injection. Black solid line: the gain by simulation. Red dash line: the gain after optimizations. Green dot line: the gain before optimizations

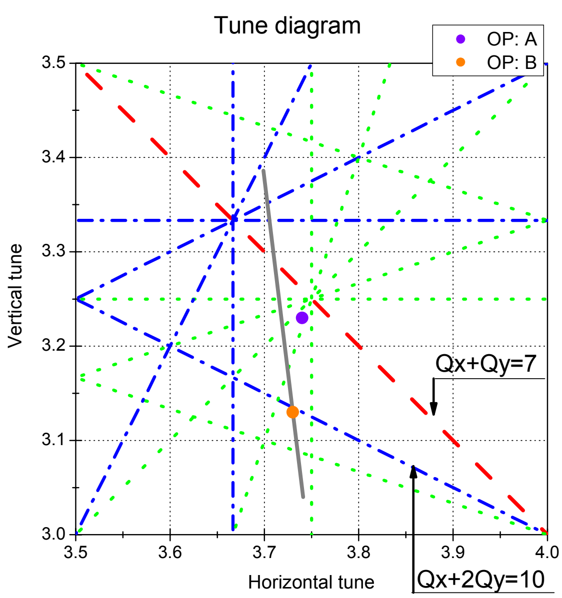

Figure 4: Tune diagram and measurement line of tune survey. Grey solid line: measurement line of tune survey, red dash: 2nd-order resonance line, blue dash dot: 3rd-order resonance line, green dot: 4th-order resonance line. Operation point (OP) A is (Qx, Qy)=(3.74, 3.23), and operation point B is (Qx, Qy)=(3.73, 3.13).

TUNE SURVEY

Tune survey was carried out in order to optimize the vertical tune with long lifetime. Fig. 4 shows the resonance lines and the measurement line of the tune survey in a tune diagram.

The result of tune survey under the coasting beam is shown in Fig. 5. The beam intensity is low by the influence of 2nd-order resonance line (Qx+Qy=7) and 3rd-order resonance lines where the vertical tune is higher than 3.3. There are two optimum tune regions from 3.10 to 3.15 and 3.23 to 3.30.

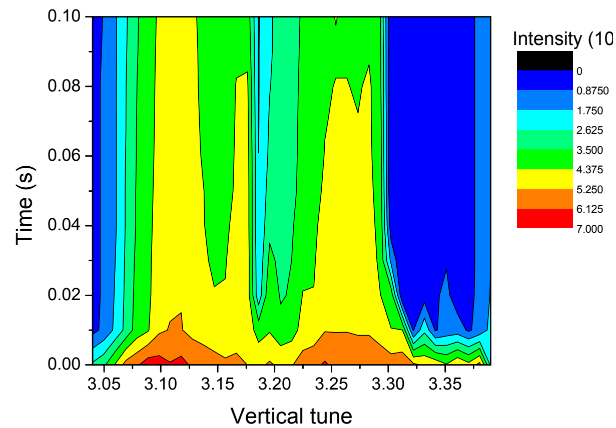

Figure 5: Intensity as a function of the vertical tune and time after injection.

In the bunched beam, on the other hand, the tune spread due to the space charge effect is enhanced. Under the bunched beam, Laslett tune shift [4] is ΔQy>0.1 when the intensity is higher than $6{\cdot}10^{10}$ ppp. Fig. 6 shows the beam-intensity dependency of the vertical tune in the bunched beam.

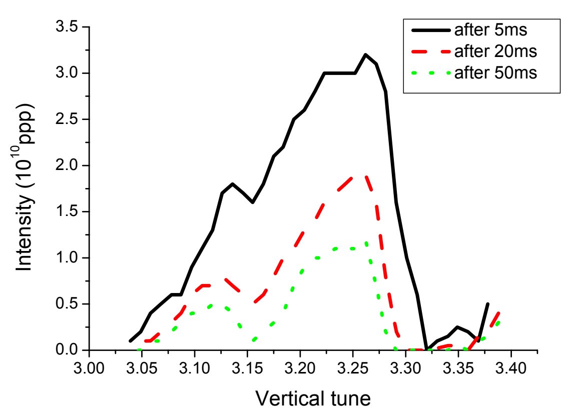

Figure 6: Intensity as a function of vertical tune when beam is bunched after 5ms (black solid line), 20ms (red dash line), and 50ms (green dot line).

Considering the tune shift due to the space charge effect, the intensity under the vertical tune of 3.23 (point A in fig. 4) was compared with that under 3.13 (point B in fig. 4). It seems that a beam-loss was caused by integer resonance of Qy=3 when the vertical tune is 3.13, because

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of the space-charge tune-shift in the higher intensity. On the other hand, the beam-loss was caused by 3rd-order resonance of Qx+2Qy=10 under Qy=3.23. Fig. 7 shows the comparison of the beam-intensity at Qy=3.23 with that at 3.13 under the horizontal tune about Qx=3.74.

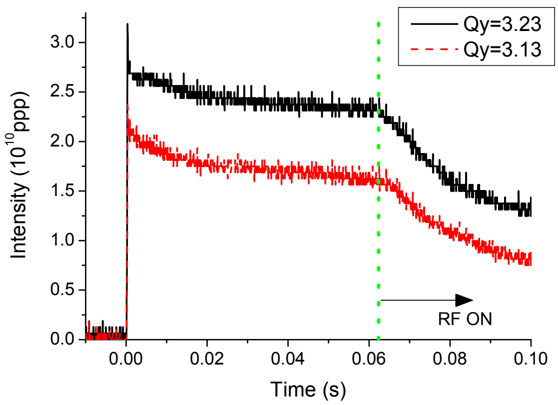

Figure 7: Comparing the beam-intensity when vertical tune is 3.23 with one when the vertical tune is 3.13.

Under both the conditions of Qy=3.23 and of 3.13, the beam-loss was more than 50%. The vertical-tune distance between the bare tune and the main resonance line are around ΔQy=0.1 under Qy=3.23 and ΔQy=0.13 under Qy=3.13, respectively. The injected intensity under Qy=3.13 was low compared with that under Qy=3.23, owing to the resonance line of Qx+2Qy=10. In order to avoid the integer resonance of Qy=3, thus, the tune of Qy=3.23 is much efficient considering the space charge tune-shift in the high intensity. However, since the beam-loss in this tune is caused by crossing the Qx+2Qy=10, the sextupole-error correction will be necessary to suppress the beam-loss.

SUMMARY

First, at the HIMAC synchrotron, the multiturn injection was optimized in order to increase the injected beam intensity. Through the simulation, the horizontal tune and beta function of injected beam at injection point were chosen to be Qx=3.74 and βx=0.75m. Under this condition, the beam-injection line was re-designed so as to match the twiss parameters with the multiturn-injection conditions. Consequently, the stored intensity after the multiturn injection was successfully increased by a factor around two. The vertical beam distribution measured by MCP was in good agreement with that of the simulation, because of the sufficient matching at the injection point. Second, tune survey was carried out. The vertical tune was chosen to be 3.13 or 3.23. Resonance line are mainly 2nd–order resonance Qx+Qy=10, 3rd-order resonance Qx+2Qy=10 and integer resonance Qy=3. The vertical tune Qy=3.23 gave the higher intensity. However, the beam-loss is caused by the resonance line Qx+2Qy=10 under this vertical tune. Therefore, a correction of sextupole error is necessary for minimizing beam-loss across the resonance line Qx+2Qy=10.

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