STUDY OF MULTITURN INJECTION AT HIMAC SYNCHROTRON

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Abstract

At the HIMAC synchrotron, a multiturn injection was improved in order to increase the intensity. The improvements are followings: (1) Changing the working point, (2) Optimisation of the beam-injection line to match the twiss parameters of an injection beam with those in the injection point of the ring, (3) COD correction and (4) Optimisation of bump orbit. Consequently, the gain of the multiturn injection was increased by 50%.

1. 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 1900 at June 2004. Based on the experience for ten-years 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 optimised and improved at the HIMAC synchrotron. The improvements for the multiturn injection were followings: (1) Changing the working point to avoid an integer resonance even when a space-charge effect shifts the tune at a high intensity, (2) Matching the twiss parameters of an injection beam with those in the injection point of the ring, (3) COD correction and (4) Optimisation of bump orbit. Consequently, the gain of the multiturn injection was increased by 50%. The experiment and simulation results are described in this paper.

2. OPTIMISATION AND EXPERIMNT

2.1 Working point

At present, the multiturn injection has been operated at the working point of (3.68, 3.13). The simulation was carried out in order to verify whether this working point is optimum one. Figure 1 shows the dependency of the beta function of the injection beam at different horizontal-tune values. 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 form Fig. 1 that the highest gain is obtained at the horizontal tune of 3.75. Since the beta function of the injection beam is too small, however, transmission efficiency through the beam-injection line is considerably reduced. On the other hand, the gain at the tune of 3.68 is low compared with that at 3.72. Therefore, the horizontal tune was chosen to be 3.72. Concerning the vertical tune, it is changed from 3.13 to 2.88, in order to avoid a vertical integer resonance of 3 due to the space-charge tune-shift in the higher intensity.

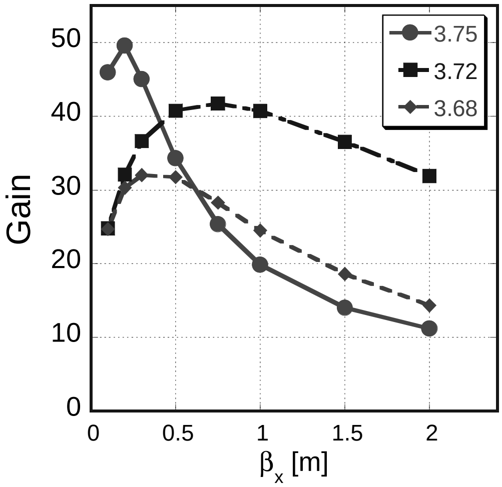

Fig. 1: The multiturn-injection gain as a function of beta function of the injection beam at three different horizontal-tune values.

2.2 Optimisation of beam injection line

The emittance of the beam from the linac cascade was measured to be around 10 π·mm·mrad, while the designed one was 26.4 π·mm·mrad. The beam optics in the beam-injection line was re-designed, therefore, which was taken the change of working point into account. In this re-design, the old optics [3] was reconstructed by using the actual parameters of the focusing elements. As a result, it was found that there was the position with a large beta-function and a part of beam was lost there. Thus, the new optics was designed not only to optimise the twiss parameters of the injection beam for the multiturn injection, but also to suppress such large beta-function. The old and the new optics are shown in Fig. 2. Owing to the new design, the transmission efficiency was increased to 95% from 85% in the old optics.

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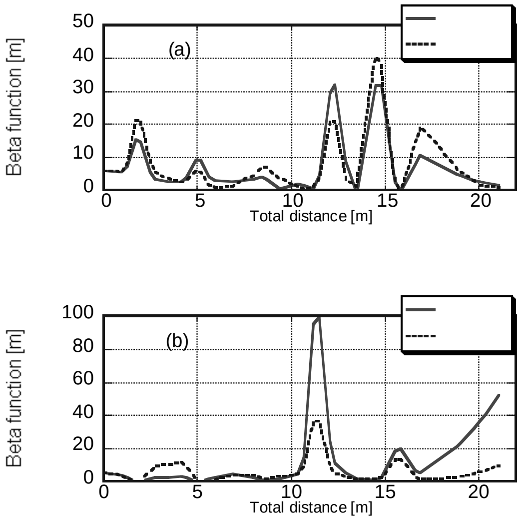

Fig. 2: Beta function by the old (solid line) and by the new optics (broken line) in the beam-injection line. (a) The horizontal and (b) the vertical direction.

In order to verify the vertical matching between the twiss parameters of injection beam and those at injection point of the ring, the vertical profile of the circulating beam after multiturn injection was measured by using non-destructive beam profile monitor with multi-channel plate [4]. Figure 3 shows the measurement result. As can be seen in Fig. 3, the vertical beam size by the new optics is considerably small compared with that by the old one: the FWHM beam size by the new optics was reduced to 13 mm from 22 mm by the old one, which corresponded to 19 from 40 π·mm·mrad of the vertical emittance. The vertical matching was considerably improved, although it is not perfect.

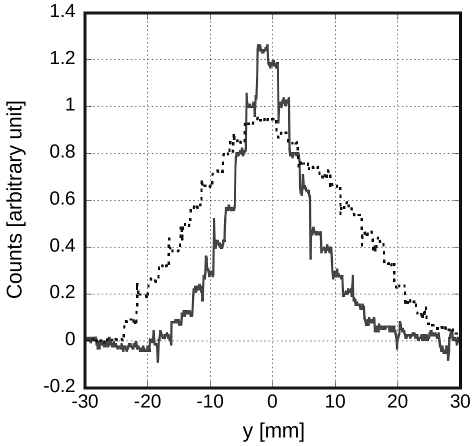

Fig. 3: The vertical profile of the circulating beam in the ring. The solid and the dotted line show the beam profile with the new optics and that with the old one, respectively.

2.3 COD correction and optimisation of bump orbit

The horizontal COD in the ring was corrected to sufficiently increase the ring acceptance. Figure 4 shows the correction result. The COD in the injection point was corrected to be around 1 mm, while that before correction was around 10 mm.

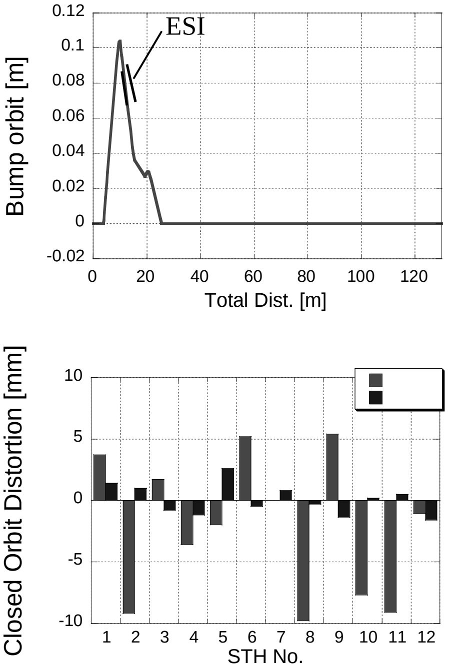

Fig. 4: Horizontal COD correction. Red and blue column indicate COD before and after correction, respectively. The horizontal axis shows the correction-magnet number.

After COD correction, the bump orbit was also optimised so as to obtain maximum intensity. Further, the optimisation was verified by measuring the partial efficiency. This method is based on the following consideration. The partial efficiency as a function of injection time is changed when the optimisation is not perfect. Comparing the injection-time dependency of the measured partial-efficiency with that of the simulation one, it is possible to verify the bump-orbit optimisation. In this measurement, the time width of the injection beam was set to be 50 μs, and the injection start timing was shift by 50 μs from 0 to 350 μs. The partial efficiency at each injection timing was measured by observing the intensity at 1 ms after the injection. The measurement result is shown in Fig. 5. The partial efficiency before optimisation is high at early timing (0-50 μs) of the injection compared with that after optimisation, and it is almost zero at late timing (300-350 μs) even when the beam is still injected. It suggests that the bump-orbit size is smaller than the distance between the central orbit and the septum of the electrostatic inflector (ESI). On the other hand, the partial efficiency after optimisation is relatively low at the early timing, while it has gain even at the late timing. Further, the total gain after optimisation is much higher that that before optimisation. These results are consistent with the simulation ones.

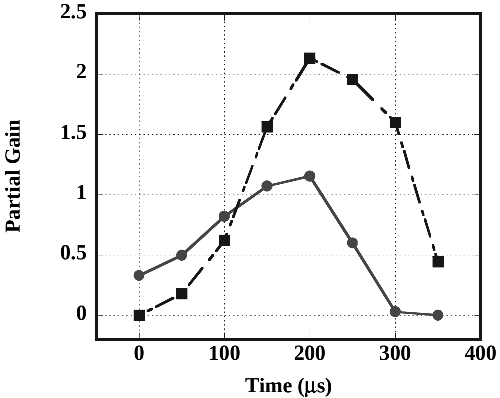

Fig. 5: Partial efficiency as a function of injection time. The solid line with closed circles and the broken line with closed squares indicate the partial efficiency before optimisation and that after optimisation, respectively.

2.4 Injection gain

After the optimisations mentioned above, the total injection gain after optimisations is compared with that before optimisations, as shown in Fig. 6. The total gain after optimisations was increased by around 50%, compared with that before optimisations. On the other hand, the stored intensity after optimisations was increased to $8.6 \cdot 10^{10}$ from $4.6 \cdot 10^{10}$ ions before optimisations, which was brought by increasing the multiturn-injection efficiency and the transmission efficiency trough the beam-injection line. However, the measured gain after optimisations is lower by 25% than the gain predicted by the simulation under ideal conditions. It seems that one of sources for such discrepancy is a beam loss between the septum magnet and the ESI.

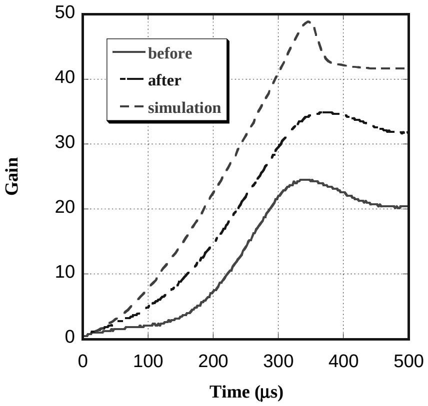

Fig. 6: The injection gain during the multiturn injection and 150 μs after the end of the injection.
The solid line: the gain before optimisations, the dash-dotted line: after optimisation and the broken line: the simulation line.

3. SUMMARY

At the HIMAC synchrotron, the optimisation for the multiturn injection was carried out in order to increase the injected beam intensity. The optimisation parameters were determined according to the simulation result. In the optimisation, at first, the working point was changed to around integer ± 1/4 in the horizontal direction and to avoid crossing an integer resonance due to a tune-shift by the space-charge effect in the vertical direction. Under this working point, the beam-injection line was re-designed so as to match the twiss parameters with the multiturn-injection conditions. As a result, the vertical emittance in the ring was decreased to 19 from 40 π·mm·mrad. Owing to the COD correction and the optimisation of the bump orbit, consequently, the stored intensity after the multiturn injection was successfully increased by a factor around 2.

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