OPTICAL MATCHING OF SLOWLY EXTRACTED BEAM WITH TRANSPORT SYSTEM AT HIMAC

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Abstract

Matching of twiss parameters between the ring and the transport line plays an important role in controlling the beam size. At HIMAC, thus, matching of twiss parameters was realized by using the simulation result. As a result, it was verified that the calculation result was in good agreement with the measurement of the beam size. The distribution of the beam profile in the transport line was also in good agreement with the particle tracking result. This paper describes the controllability of the slowly extracted beam and related development at HIMAC.

INTRODUCTION

Clinical trials of heavy ion therapy in HIMAC (Heavy Ion Medical Accelerator in Chiba) [1,2] started on June 1994, and treatments of more than 2000 patients were successfully completed by April 2005. On the other hand, as one of the objectives at HIMAC, new technologies in heavy-ion therapy and related basic and applied research have been developed.

Concerning the scanning irradiation [3-5], recently, the development of the RF-knockout extraction [6,7] has been considerably progressed. The controllability of the beam size is important not only for the scanning irradiation, but also for the physics and the other applications. Beam-size control is one of most essential techniques for the beam-scanning method, because the beam size should be kept constant during an irradiation, even for various extracted energies. At the HIMAC synchrotron, therefore, the optics of the slowly extracted beam has been studied to achieve the controllable beam size. In order to deliver the beam size as predicted, the twiss parameters, the emittance and the dispersion function at the extraction channel should be clearly defined as an initial condition of the transport optics. Since RF-knockout extraction employs the constant separatrix, we can clearly define the twiss parameters of the slowly extracted beam. Finally, we obtained following results: 1) Dispersion free optics of the transport line was verified by the dispersion function measurement, 2) It was verified that the calculated envelopes were in good agreement with the measured beam sizes, 3) Estimated beam profile by using the simulation was in good agreement with the measurement, and 4) Controlling the beam size was verified by demonstrating the small divergence beam of less than 0.1 mrad. This paper describes the controllability of the slowly extracted beam and related development at HIMAC.

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TWISS PARAMETERS OF A SLOWLY EXTRACTED BEAM

To control the beam size as predicted, the twiss parameters (including emittance and dispersion function) at the extraction channel should be defined as an initial condition of the transport system. In order to define the twiss parameters of a slowly extracted beam at the HIMAC synchrotron, a simulation was carried out. As a result, the rms emittance and twiss parameters are calculated to be 0.03 [π mm·mrad] and (βx,αx)=(300,20), (Dx,$D'x$)=(-0.5,0.19), respectively. Figure 1 shows the simulation result for deferent momentum to define the dispersion function. In order to verify the twiss parameters of the extracted beam, a simple method [8] to measure the outgoing separatrix using two tantalum rods was proposed and verified. We compared the simulation result between the measurement results of outgoing separatrix. The measurement supports the twiss parameters calculated by the simulation.

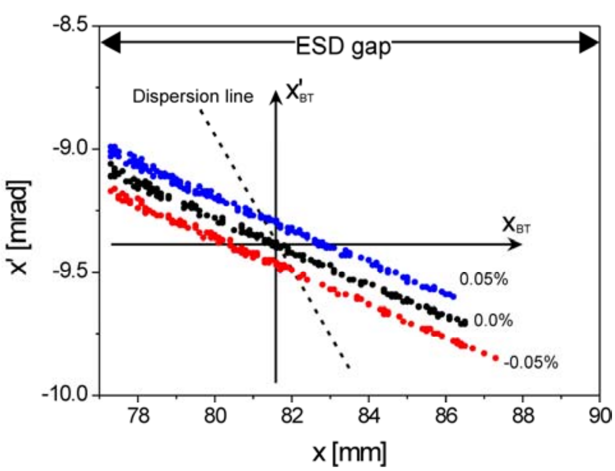

Figure 1: Simulation result of an extracted beam at the entrance of the extraction channel for each momentum (Δp/p) of –0.05%, 0.0% and 0.05% from the bottom.

COMPARISON BETWEEN SIMULATION AND EXPERIMENT

Since the estimated twiss parameters of the slowly extracted beam was slightly different from the original design value, the beam optics in the transport line was re-designed in order to match the twiss parameters. In this calculation, the magnetic parameters were adjusted so as not to lose the beam under the present acceptance in the

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transport line. Using the new optics, an experimental test was carried out. The dispersion function was measured while changing the momentum of the circulating beam by changing the acceleration RF frequency. Figure 2 shows a comparison between the measurement and the calculation. It was observed that the achromatic condition was successfully realized in the horizontal plane. For the vertical plane, on the other hand, the initial dispersion function was estimated to be Dy=0.1 for reproducing the measurement result. It seems that a vertical COD in the ring cause vertical dispersion.

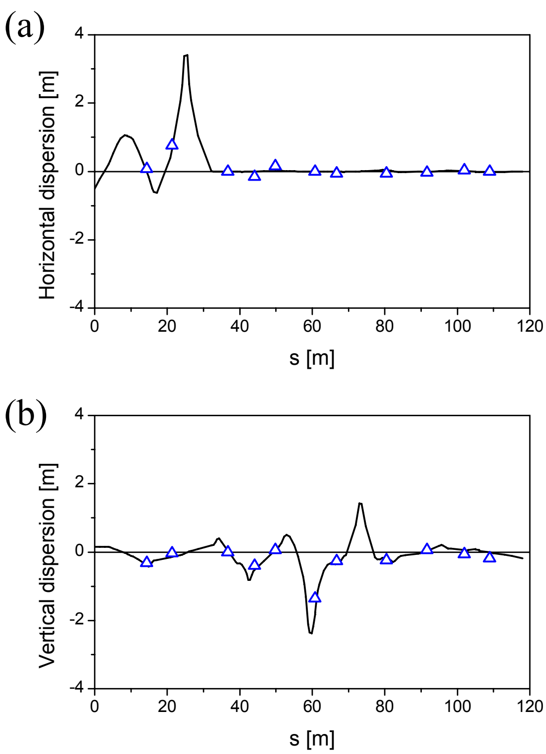

Figure 2: Comparison of the dispersion function between the estimation (line) and the measurement (triangles). (a) horizontal and (b) vertical.

Further, the beam size was measured at each profile monitor in the transport line. The calculated beam envelopes in both the horizontal and vertical directions were compared with the measured beam size (2σ), as shown in Fig. 3. The envelopes were calculated under the following conditions: The horizontal beam envelope was calculated by using the initial condition of the twiss parameters and the 2σ-emittance estimated by using the simulation result. The vertical twiss parameters as the initial condition were set to be the same as that of the ring at the entrance of the electrostatic deflecter (ESD), which is the initial point for the transport calculation. The vertical 2σ-emittance was estimated to be 2.0 [π mm·mrad] from the circulating beam size measured by the non-destructive profile monitor [9]. The momentum spread (2σ) for the envelope calculation was set to be ±0.05% obtained by a Schottky measurement. In this calculation, the estimated dispersion function in Fig. 2 was used. The measured envelope of the beam size is in good agreement with the calculated one. Furthermore, the beam-size was measured for a wide momentum-spread beam.

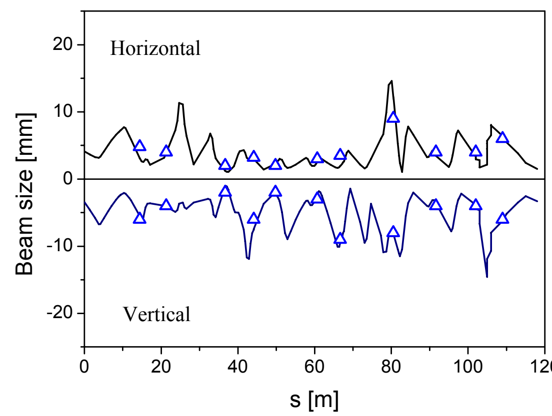

Figure 3: Comparison of the beam envelope (2σ) between the calculation (line) and the measurement (triangles) values.

To estimate the beam profile at each profile monitor in the transport line, on the other hand, the particle tracking is necessary. By using the simulation result of the extracted beam and the transfer matrix of the transport line, we can estimate the horizontal beam profile. Owing to the matching of the twiss parameters, this result is also in good agreement with the measurement at each profile monitor in the transport line. By changing the optics, as shown in Fig. 4, we could also demonstrate the small divergence beam in the horizontal plane owing to their small emittance. Since the quadrupole magnets from s=80 [m] to 120 [m] were turned off to obtain long drift space, in this case, we could estimate the horizontal divergence of the delivered beam to be less than 0.1 [mrad].

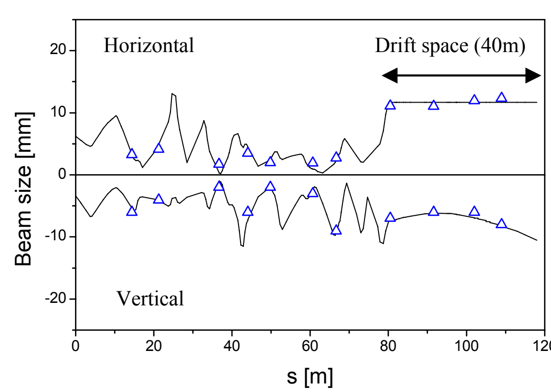

Figure 4: Comparison of the beam envelope (2σ) between the calculation and the measurement (triangles) with another optics for a horizontally small divergence beam.

RELATED DEVELOPMENT

Modification of Non-Gaussian Distribution

The slowly extracted beam has Non-Gaussian distribution. In order to modify it and to supply Gaussian distribution beam while keeping beam size at iso-center, we have proposed to use thin scatterer in the transport line as shown in Fig. 5. The change of twiss parameters and emittance growth at the scatterer are formulated in [10]. Thus, the optical elements before and after the scatterer are controlled to obtain Gaussian distribution beam and to control the beam size. In the preliminary test result at HIMAC, Gaussian distribution in horizontal plane was verified. Further, the controllability of the beam size in both plane were also verified.

Since this technique can make it possible to produce same emittance in both horizontal and vertical planes, it will contribute to the design of a complicated transport system, such as a rotating gantry, while compensating Non-Gaussian distribution of a slowly extracted beam.

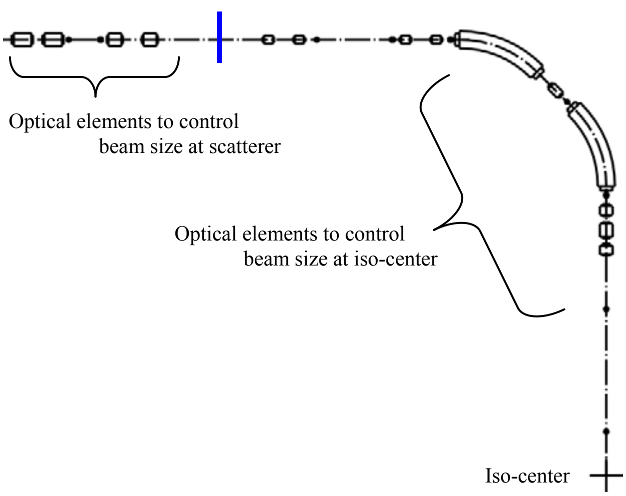

Figure 5: Configuration to produce Gaussian distribution by using thin scatter.

Development for Turn-Key Beam Delivery

In order to increase the number of patients per day, we have studied toward the realization of the turn-key beam delivery [11]. The magnetic field of each element slightly changed from day to day. As a result of the study, the followings were found. Slight change of the magnets in the transport line doesn't affect to the beam quality, such as position, profile and intensity. However, slight change of the horizontal tune strongly affect to the beam quality, as shown in Fig. 6, because the synchrotron employs the resonant extraction. Slight change of the extraction angle will be suppressed by ESD.

SUMMARY

To realize the matching of twiss parameters between the ring and the transport line for the controllability, it is necessary to obtain the twiss parameters of the extracted beam at the extraction channel as an initial condition of the transport line calculation. Thus, we define the twiss parameters of the slowly extracted beam by using the results of the simulation and the outgoing separatrix measurement. As a result, the controllability of the slowly extracted beam was demonstrated. It was also verified that the calculated envelope was in good agreement with the measurement of the beam size. The particle tracking made it possible to predict the beam profile in the transport line.

Recent result to produce Gaussian distribution by using thin scatterer will supports the design and the operation of the rotating gantry and the scanning irradiation system.

Development for turn-key beam delivery is in progress. The turn-key operation of accelerator will start from this September.

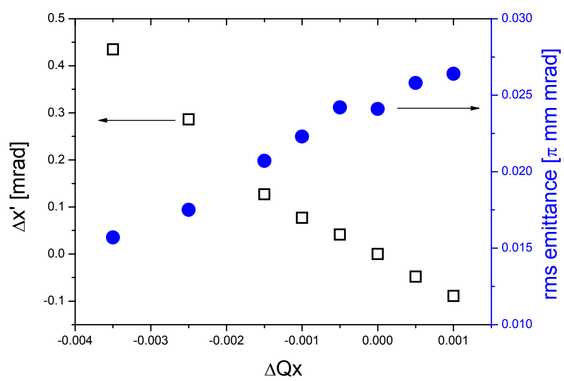

Figure 6: Horizontal tune dependence of extraction angle (square) and extracted emittance (blue circle), as a result of simulation.

ACKNOWLEGMENT

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