OPTICAL MATCHING OF SLOWLY EXTRACTED BEAM WITH TRANSPORT SYSTEM

T. Furukawa[a,b #], K. Noda[b], S. Shibuya[c], T. Fujimoto[c], M. Muramatsu[b], E. Urakabe[b], S. Sato[b], T. Uesugi[b], M. Kanazawa[b], M. Torikoshi[b], H. Kawai[a], E. Takada[b] and S. Yamada[b]
a) Graduate School of Science and Technology, Chiba Univ., Chiba, JAPAN
b) National Institute of Radiological Sciences, Chiba, JAPAN
c) AEC, Chiba, JAPAN

Abstract

The matching of the optical function between the ring and the transport line plays important role in order to control the size of pencil beam precisely in the scanning irradiation for cancer therapy. For this purpose, the optical matching of the slowly extracted beam with the transport system has been investigated at HIMAC. As a result, it was verified that the beam size of the slowly extracted beam could be controlled owing to the optical matching. This technique will also make it easier to design the complicated transport system such as a gantry.

1 INTRODUCTION

Heavy-ion beams have attracted growing interest for cancer treatment due to their high dose localization at the Bragg peak as well as high biological effect there. Recently, therefore, heavy-ion cancer treatments have been successfully carried out at various facilities around the world. On the other hand, beam-scanning irradiation method, such as spot and raster scanning, has been developed around the world in order to achieve a high irradiation accuracy, even for an irregular-shaped target. The emittance of the extracted beam along with its position and angular stability are critically important for creating pencil beams used in scanning irradiation for conformal 3-D irradiation. The matching of the optical function between the ring and the transport line plays important role in order to control precisely the size of pencil beam. For this purpose, the optical matching of the slowly extracted beam with the transport system has been investigated at HIMAC (Heavy Ion Medical Accelerator in Chiba) [1]. Since the phase-space distribution of the slowly extracted beam is a kind of a thin string, a conventional method [2] to measure the optical function and the emittance by using the beam profile, in which Gaussian distribution of the beam is assumed, is difficult to apply for the slowly extracted beam.

At HIMAC, the RF-knockout slow extraction method [3-4] has been routinely used for therapy and the experiments of physics and biology. In the RF-knockout extraction, to keep the emittance constant during the extraction is easier than the ordinary slow-extraction owing to the constant separatrix. However, the verification method of beam matching has not yet been developed. Thus, the method to measure the outgoing separatrix is proposed and verified by using thin rod. Since the outgoing separatrix was measured, the optical function of the extracted beam at the entrance of the extraction channel can be estimated. This result suggested the mismatching of the dispersion from the design value. Thus, the optical parameters of the transport line are readjusted to match with the extracted beam. Finally, it was verified that the optical matching of the slowly extracted beam with the transport system.

2 OPTICAL CHARACTERISTICS OF SLOWLY EXTRACTED BEAM

In order to estimate the optical characteristics of the extracted beam, a simple method [5] to measure the outgoing separatrix using two tantalum rods has been proposed and verified at the HIMAC synchrotron. By measuring the extracted beam intensity with inserting two rods into the ring, the intensity spectrum for different position of second rod can be observed for each position of rod1. As a result, one of the outgoing separatrix for the extraction can be measured. As shown in Fig. 1, the result of the measurement is in good agreement with the simulation result. This simulation is carried out by the particle tracking code [6] for the RF-knockout extraction. Since there is the electrostatic deflector (ESD), the particles into 77~90mm will be extracted.

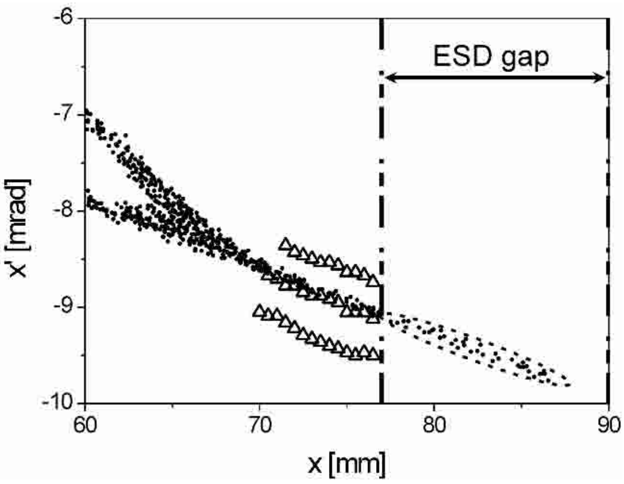

Fig. 1. Triangles represent outgoing separatrix for each momentum of –0.3%, 0.0% and 0.3% from the bottom, as a result of the experiment. Closed circles are simulation result of the separatrix. The area enclosed by dotted line shows extracted beam.

t_furu@nirs.go.jp

Since the simulation result well reproduces the experimental result, we can estimate the optical property of the extracted beam at the entrance of the extraction channel by using the simulation result. Firstly, the twiss-parameters at the entrance of the extraction channel are estimated by fitting the beam as an ellipse (enclosed by dashed curve in Fig. 1). Secondly, the dispersion function is estimated by using the extracted beam center of the position and angle for each momentum. Fig. 2 shows the simulation result of the extracted beam at the entrance of the extraction channel for each momentum of –0.05%, 0.0% and 0.05%, respectively. These results are summarized at table 1, comparing with the original design value.

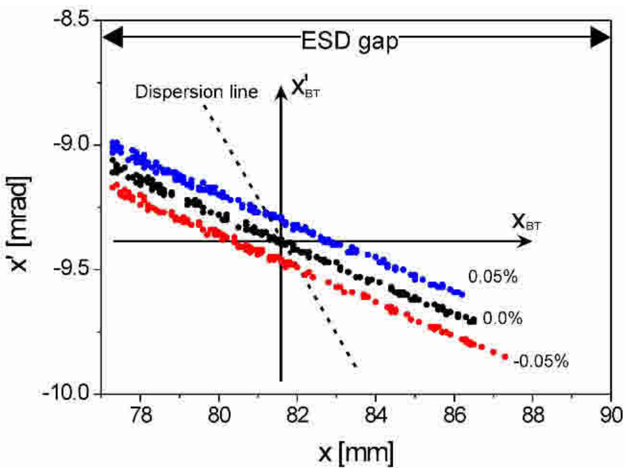

Fig. 2. Simulation result of extracted beam at the entrance of the extraction channel for each momentum of –0.05%, 0.0% and 0.05% from the bottom.

Table 1: Comparison of twiss-parameters and dispersion function at the entrance of the extraction channel

	Original design	**Estimated by simulation**
β_x	5.0m	15m
α_x	0.0	1.0
ε_x	10π mm mrad	1.5π mm mrad
D_x	-0.5	-0.5
D'_x	0.0	0.19

The initial condition of the beam line is defined to be the parameters estimated by the simulation. Using these parameters, the optics of the beam transport line was re-calculated in order to match the optical function. In the calculation, the magnetic parameters were adjusted not to loss the beam under the present magnets and aperture.

3 COMPARISON BETWEEN SIMULATION AND EXPERIMENT

Using this new optics, the experimental test was carried out. The transport line from the HIMAC upper ring to the biological experiment room was used. This line is including the vertical beam line and 11 profile monitors. In the experiment, the carbon ions with an energy of 400 MeV/u were extracted from the synchrotron through the RF-knockout slow-extraction method.

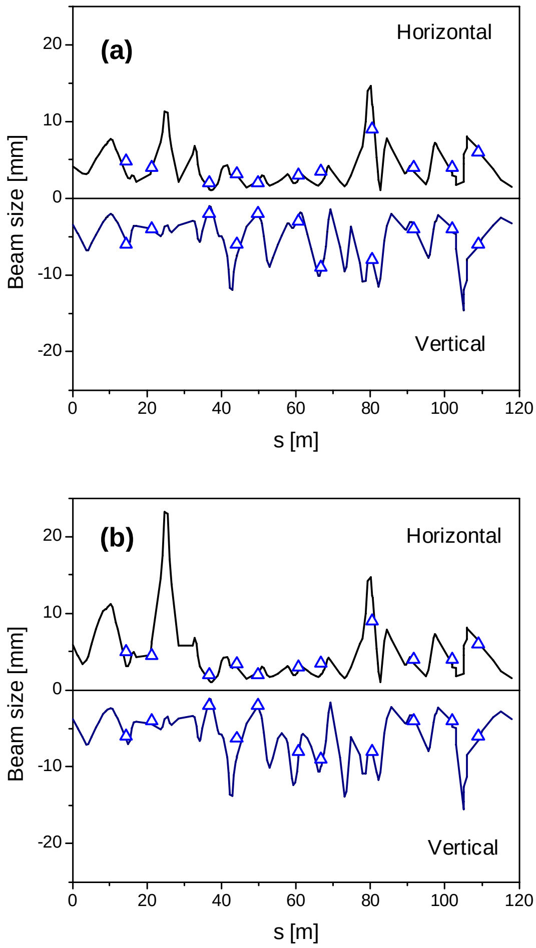

Fig. 3. Comparison of the beam envelope (2σ) between the calculation and the measurement (triangles). (a) the momentum spread (2σ) is ±0.05% and (b) ±0.4%.

The beam size was measured at each monitor in the transport-line. The both beam envelopes of horizontal and vertical were compared with the measured beam size as shown in Fig. 3 (a). The emittance (2σ) and the momentum spread were estimated to be (1.0, 2.0) [π mm mrad] and ±0.05%. In this calculation of the beam envelope, the estimated dispersion function, as shown in Fig. 4, was used. The achromatic condition was successfully realized. Further, not only the dispersion, but also the measured beam size is in good agreement with the estimation at each monitor in the transport line. As shown in Fig. 3 (b), even for the beam having wide momentum spread (±0.4%), the measured beam size is in good agreement with the estimation. It was experimentally verified that the extraction efficiency was kept at more than 95% even for the beam having such wide momentum spread.

On the other hand, we can estimate the horizontal beam profile at each profile monitor by using the simulation result of the extracted beam and the transfer matrix of the transport line. Owing to the matching of the optical functions, this result is also in good agreement with the measurement at each profile monitor. The typical result of this is shown in Fig. 5.

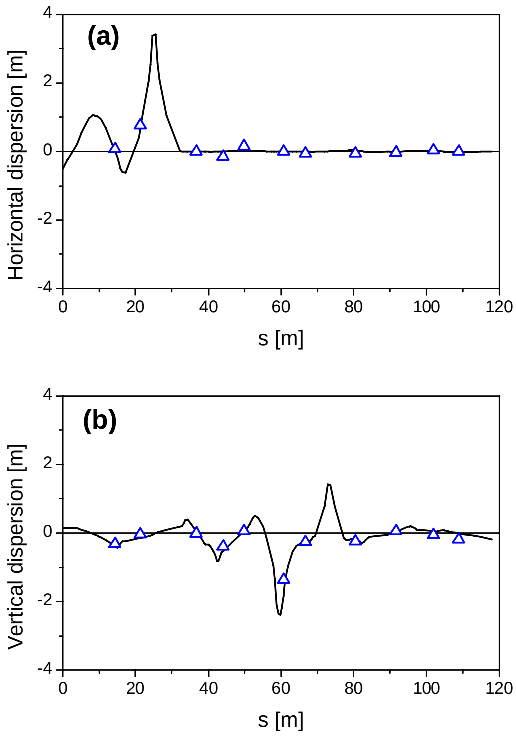

Fig. 4. Comparison of dispersion function between the estimation (line) and measurement (triangles), (a) horizontal and (b) vertical.

4 SUMMARY

The optical parameters of the transport line were readjusted to match the optical function with the extracted beam. Finally, it was experimentally verified that the optical matching of the slowly extracted beam with the transport system. The measured beam profile and dispersion function is in good agreement with the simulation at each monitor in the transport line. Further, the HIMAC transport system can deliver the beam having wide momentum spread (±0.4%) without any beam loss.

This technique allows us to control the beam size precisely as planned. Further, these results will contribute to the designer of the complicated transport system, such as a gantry, together with the slowly extracted beam.

ACKNOWLEGMENT

The authors would like to express their thanks to members of the Department of Accelerator Physics and Engineering at NIRS for continuous encouragement. This work has been performed as a part of Research Project with Heavy-Ion at NIRS-HIMAC.

REFERENCES

[1] Y. Hirao et al, Nucl. Phys. A528 (1992) 541c.
[2] M. Giovannozzi et al, CERN PS (CA) 98-032, (1998).
[3] K. Noda et al, Nucl. Instr. and Meth. A 374 (1996) 269.
[4] T. Furukawa et al, Proc. 8th EPAC, Paris, 2002, p. 2739-2741.
[5] T. Furukawa et al, "New Approach Toward Optimized Resonant Slow-Extraction", Nucl. Instr. and Meth. A, in press.
[6] T. Furukawa and K. Noda, Nucl. Instr. and Meth. A 489 (2002) 59-67.

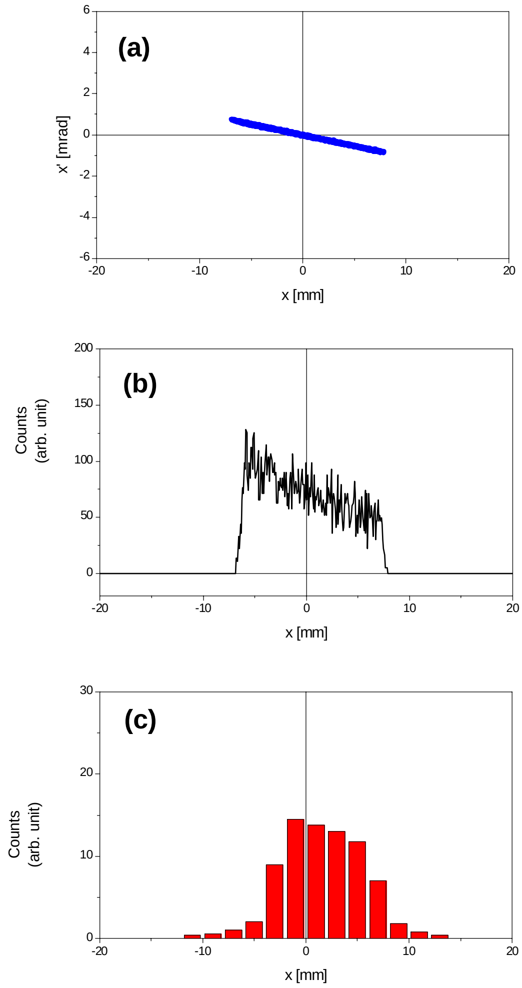

Fig.5. Comparison of the horizontal beam profile between the simulation and the experiment. (a) Estimated phase-space distribution, (b) horizontal profile estimated by the simulation and (c) the measured profile.