DEVELOPMENT TOWARD TURN-KEY BEAM DELIVERY FOR THERAPEUTIC OPERATION AT HIMAC

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Abstract

Since 1994, more than 2600 cancer patients have been treated by carbon ion beam at HIMAC. In order to treat more patients with more flexible scheme, it is necessary to minimize the beam tuning time. Therefore, we have studied characteristics of beam behavior with present parameters and investigated remedy for daily variation. In this paper, we report about our investigation and present result of the development toward turn-key beam delivery for therapeutic operation.

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 2600 patients were successfully completed by June 2006. At HIMAC, we deliver heavy ion beams to cancer therapy during daytime and to experiments during night. Various ion species are used in experiments while therapeutic beam is confined to carbon ion with different beam energy. Procedure to change beam energy and it takes 15 minutes to adjust parameters per beam course at the present stage.

Number of patients increases year-by-year and reached more than 400 in the last fiscal year. In order to treat more patients with more flexible scheme, it is necessary to decrease the time to change the beam energy and course including the beam tuning time. Thus, we have studied the reproducibility of the beam during therapeutic operation at HIMAC toward the realization of the turn-key beam delivery (i.e., without tuning / adjustment at each time of beam energy change.) [3,4]. For this purpose, the accelerator needs high reproducibility to skip manual tuning. Further, the irradiation system needs to assure dose uniformity. In this paper, we report about our investigation and present result of the development.

PRESENT STATUS OF MACHINE

Present Status of Beam Tuning

Figure 1 shows bird's eye view of HIMAC accelerator complex. The HIMAC accelerator complex consists of two synchrotron rings injector linac chain. The extracted beams from the ring by means of RF-knockout extraction method [5,6], are delivered to treatment rooms through HEBT (High Energy Beam Transport) lines. Three treatment rooms are equipped, one with a vertical beam, one with horizontal, and one with both horizontal and vertical beams. The upper ring delivers the vertical beam, while the lower ring deliver the horizontal beam.

At present, it takes around 15 minutes to change the beam energy. The procedure is as the following. Firstly, operator changes preset values for magnetic current etc. from the saved set on the respective control computers. DC-type magnets (all of HEBT magnets and extraction septum magnets) are set to the maximum current and keep it about 30 seconds before setting of the preset value. After setting the preset value, it is necessary to wait around 100 seconds for the stabilization of the magnetic field. It takes about 5 minutes for the setting described above. Secondly, the operator adjusts the beam position and intensity. The beam position and intensity are measured at the end of HEBT lines with a pair of profile monitors [7]. Present criteria are that beam axis should be less than (±0.5mm, ±0.2mrad). Operators adjust final steering magnets and the beam scraper to satisfy this requirement, which takes around 10 minutes.

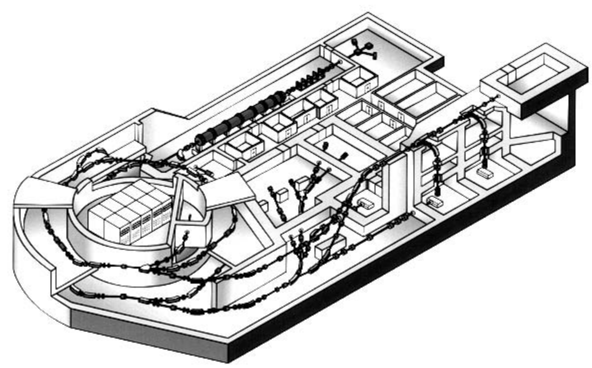

Figure 1: Bird's eye view of HIMAC.

Reproducibility of the Machine

In order to skip manual beam tuning, it is necessary to study the reproducibility of beam quality. Measurement of the beam size and intensity was carried out just before the manual beam tuning in the daily operation. The results are shown in Fig. 2. Both daily fluctuation and long term drift of the position were observed for the reproducibility of upper and lower ring. As for intensity, the fluctuation was within ±10% of the standard value of $2.0\cdot10^9$ particles per second. As can be seen in Figure 2, beam position of vertical beam line shows poor reproducibility, especially in horizontal axis, which corresponds to the extraction direction. Further, it was confirmed that large variation was observed at particular occasions; i) After high magnetic field operation (1.5T at BM) such as Si beam with energy of 800MeV/u, ii) After relatively low

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magnetic field operation (0.45T at BM) such as H beam with energy of 100MeV/u and iii) At the cold start due to holiday schedule.

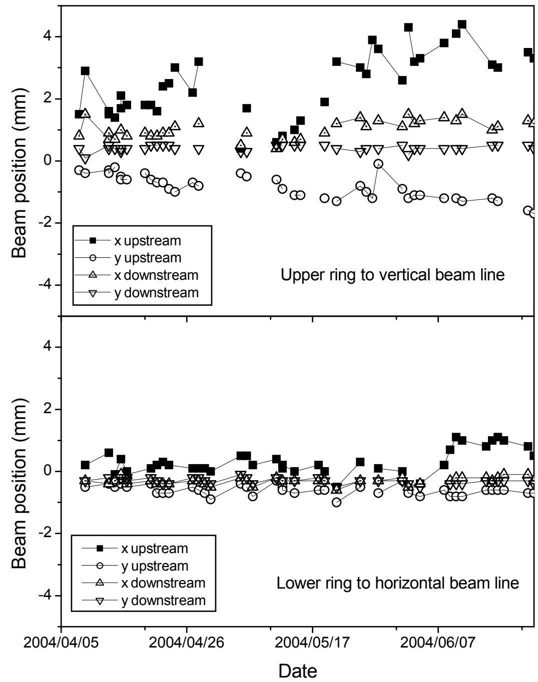

Figure 2: Reproducibility of beam position measured by two profile monitors, one located 8 m upstream of iso-center and another located 2 m upstream of iso-center.

STUDY OF ACCELERATOR

Parameters that Affect Reproducibility

As described above, reproducibility of upper ring was much poorer than that of lower ring. Further, the large variation was observed at particular procedure conditions. Therefore we have studied on relevant parameters that may cause the phenomenon of beam position change.

Cooling Water Temperature

Temperature of the cooling water for power supplies and magnets varies according to the excitation level etc. Figure 3 shows a correlation between cooling-water temperature and beam position in the vertical beam. It is seen that 7 degrees rise in water temperature in the first one hour after the cold start corresponded to more than 3 mm change of horizontal beam position. We take an extra time for reaching equilibrium temperature of cooling water in the case of cold start.

Residual Magnetic Field and Tune Fluctuation

It can be conceived that the extreme condition such as maximum energy and lower than minimum-design-value may cause variation of magnetic field via different residual magnetization. Owing to initializing procedure, the magnetic field reproducibility of the DC magnets was measured to be less than $5{\cdot}10^{-5}$ by NMR measurement. Such slight change of the magnetic field in the transport line would not affect the beam quality, such as the position, profile and intensity.

On the other hand, the magnetic field reproducibility of the pattern operation magnet was measured to be around $5{\cdot}10^{-4}$ by search-coil measurement. The slight difference of the magnetic field in the ring brings the tune difference. Since a slight change of the horizontal tune causes the separatrix size difference in the resonant slow extraction, the extraction angle and the emittance change, which were calculated by using RF-knockout simulation code [8] and shown in Fig. 4. It means the beam quality at the end of HEBT strongly depends on the magnetic field stability of the pattern operation magnet in the synchrotron ring.

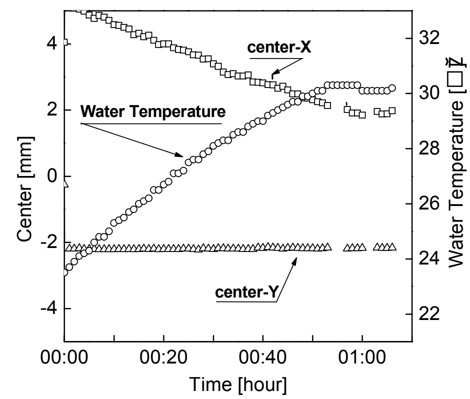

Figure 3: Relation between cooling water temperature and the beam center, which is measured just before the wobbling magnet location.

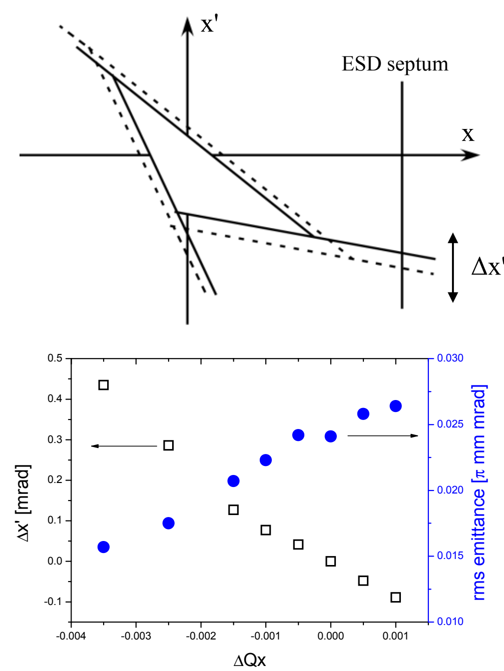

Figure 4: (a) Schematic of extraction angle fluctuation, (b) tune dependence of extraction angle and emittance by the simulation.

System to Stabilize Horizontal Tune

Since daily fluctuation of the horizontal tune strongly affects the beam quality, we have developed the system to compensate the daily fluctuation of the horizontal tune. Block diagram of correction quadrupole (CQ) is shown in Fig. 5. In this system, we employ online-monitoring system [7] and pulse-to-pulse correction. The current of CQ is changed so as to center the beam position at the profile monitor, based on measured beam response depending on the beam line and its optics. In the preliminary test results, this system makes it possible to keep the beam position and intensity constant at the iso-center.

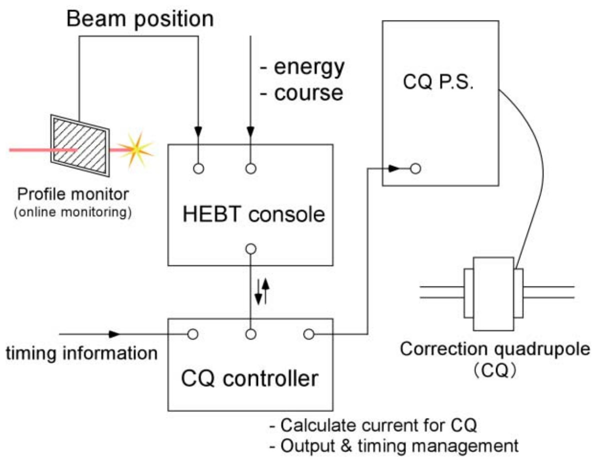

Figure 5: Brock diagram of correction quadrupole control.

STUDY OF IRRADIATION SYSTEM

For the irradiation system [9], which employs wobbler method to produce uniform field, it is required that the uniformity of the lateral dose distribution should be less than ±2.5%. Thus, we have studied the beam position and angle dependence of the dose uniformity. In order to calculate the tolerance and to compare the measurement, we made simplified montecarlo program to simulate whole irradiation system including the collimation effect. In this code, it is possible to calculate the dose distribution with the position and angle deviation and with the simplified fragment model. The typical result of the lateral dose distribution for different beam position at the center of SOBP (Spread-out Bragg peak) is shown in Fig. 6. In the case of small irradiation field, the uniform field moves in parallel owing to the beam position deviation, as shown in Fig. 6 (a). On the other hand, in the case of large field, the field doesn't move in parallel because of equipment aperture in the irradiation system, as shown in Fig. 6 (b). As a result of such kind of studies for various irradiation conditions, a position deviation at iso-center of less than 1 mm is tolerable so as not to disturb the uniformity at the HIMAC irradiation system.

SUMMARY

As a result of this study, it was found that a slight change of the magnetic field in the transport line would not affect the beam quality. However, a slight change of the horizontal tune strongly affects the beam quality because of a resonant slow-extraction. Thus, we have developed the system to stabilize the horizontal tune, which employs correction quadrupoles and online-monitoring system. Concerning irradiation system, it was found that we can ease the criteria to (±1.0mm, ±0.4mrad).

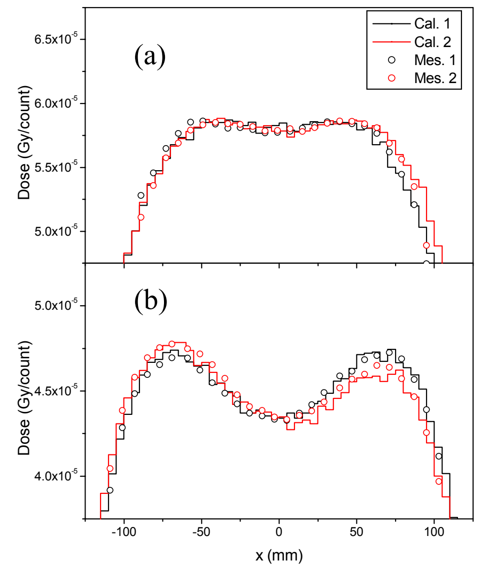

Figure 6: Comparison of lateral dose distribution between measurement and simulation with its beam position dependence (case1:Δx=0mm and case2: Δx=5mm) for different irradiation conditions: (a) φ100 mm, SOBP 60 mm and range shifter 0 mm, (b) φ200 mm, SOBP 120 mm and range shifter 130 mm.

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