BEAM TRANSPORT SYSTEM FOR THE HIMAC

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ABSTRACT

The Heavy Ion Medical Accelerator in Chiba (HIMAC) will be the first heavy ion accelerator complex for the clinical treatment of tumor in Japan. This paper describes design considerations of the beam transport system for the HIMAC.

1. Introduction

The HIMAC is an accelerator complex for the clinical treatment of tumor and is now under construction at National Institute of Radiological Sciences (NIRS).[1] The ion species which are required for the clinical treatment range from He to Ar. The beam energy is designed to be variable from 100 MeV/u to 800 Mev/u for an efficient treatment. As shown in Fig. 1, Beam transport system of the HIMAC can be divided into three region area, i.e. INJBT, EXBT, and HEBT, of which the former two are to match with synchrotron requirements.

The injection beam transport system[2] (INJBT) between the linac cascade and two synchrotron rings is designed to transport the beam alternately by using a fast switching magnet to two rings, which are placed on two stages, in the same condition for multiturn injection. The upper and the lower extraction beam transport system (EXBT) are designed to match a beam optics of a slowly extracted beam from each ring independently to that of each high energy beam transport system (HEBT). The high energy beam transport system[3] is designed to transport the vertical beam from the upper and the lower ring as well as the horizontal one from the lower one. This design allows simultaneous irradiation by horizontal and vertical beam. In addition, beams can be switched from one treatment room to an other one in a short time, keeping the good reproducibility of the beam position.

2. Injection Beam Transport System

The design conditions of the INJBT are : i) to transport the beam with the maximum magnetic rigidity of 1.42 Tm corresponding to the energy of 6 MeV/u for ions with a charge to mass ratio of 1/4, ii) to obtain a good efficiency of beam transmission and iii) to be adjustable the beam to the optical condition of the multiturn injection. The acceptance for betatron oscillation and for momentum spread are designed to be 26.4πmm mrad and $\pm 0.3\%$, respectively.

The basic requirements for the INJBT are as follows.
(a) Beam should be injected alternately to two rings in the same condition.
(b) The Twiss parameters at the entrance of each ring should be easily adjustable to match the condition of multiturn injection.
(c) Ions with different charge to mass ratio should be separated and the momentum should be analyzed for an efficient transportation and an easy beam tuning in the ring.

A fast switching magnet is designed for the simultaneous operation of two rings. The rising and the falling time of its power supply are 140 msec. The stability at the 10 msec flat top is regulated to be less than 2×10^{-4}, which is achieved in test by using a dummy load.

A required size of beam duct is determined by considering a centroid displacement of beam as well as an acceptance for the betatron oscillation and for the momentum spread. First, the beta and the dispersion function are calculated by using program MAGIC,[4] as shown in Fig. 2. Second, the position and the field strength of steering magnets and the position of profile monitors are determined for the centroid displacement caused by a misalignment and a field error of magnets to be suppressed within the size of 5 mm at a standard deviation. Third, for easy beam tuning procedure, a mirror symmetry optics is adopted to realize a waist to a waist transportation with a doubly achromatic condition. Finally, in the last section of the INJBT, a doubly achromatic condition can be realized by adjusting two quadrupole magnets, which ensures reducing an applied high voltage between a septum and an electrode of an inflector in each ring. Other additional four quadrupole magnets are prepared to match the beta function and its derivative at the entrance of the ring to the condition of the multiturn injection.

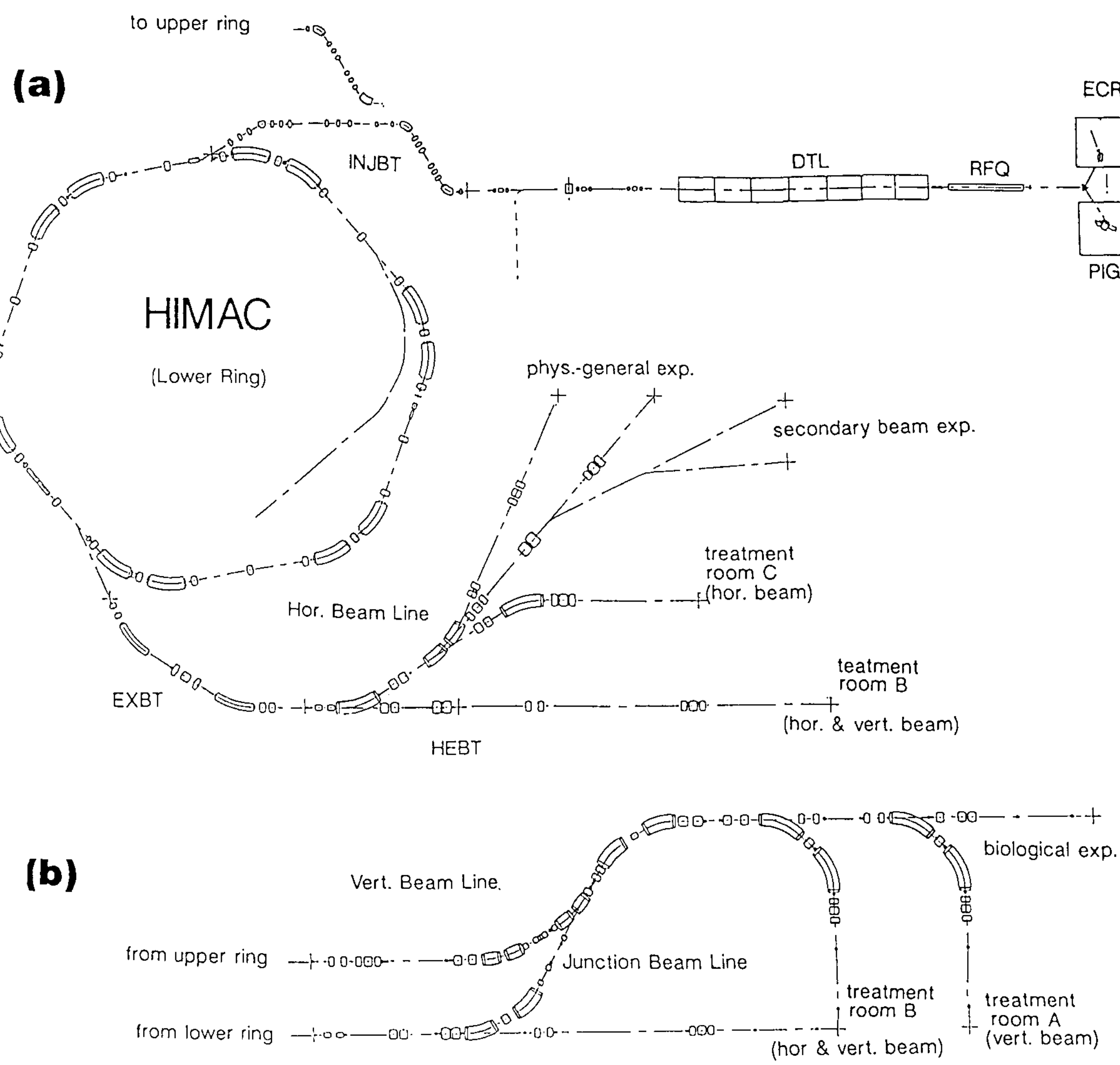

Fig. 1. (a) A plane view of the HIMAC. (b) A side view of the vertical beam line in the HEBT.

A beam momentum and a charge to mass ratio are analyzed by measuring the field strength of the first bending magnet with a NMR and by using two horizontal slits. The measurement result is referred to the field strength of the main magnets at a flat base of an excitation pattern of the ring.

3. Extraction beam transport system

The EXBT of each ring is designed to transport the slowly extracted beam to the HEBT and to match Twiss parameters to the condition at the entrance of the HEBT. The acceptance for the betatron oscillation and for the momentum spread in the EXBT and the HEBT are designed to be 10πmm mrad and $\pm 0.2\%$.

The beam optics from the entrance of the first electrostatic deflector in the ring to that of the HEBT is calculated as shown in Fig. 3, and the steering magnets and the profile monitors are assigned in the EXBT by the same manner as in the case of the INJBT.

In addition, the fast beam shutter is installed to assure an accurate irradiation dose for the clinical treatment and for the biological experiment. The beam is adjusted to an optimum condition for profile, centroid and a spill structure by using the profile monitors and the spill monitor and by tuning the beam extraction apparatuses in the ring before transportation to the HEBT.

4. High energy beam transport system

The HEBT system consists of a horizontal and a vertical beam line. The horizontal beam line is designed to transport the beam from the lower ring. The beams up to 800 MeV/u are provided to two treatment rooms (B,C) and two experimental rooms (for physics-general experiment and for secondary beam one).

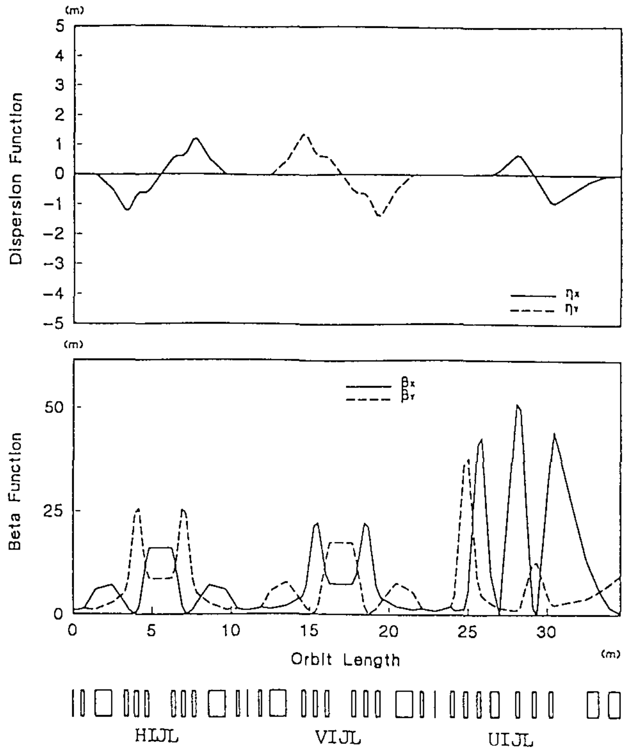

Fig. 2. Beta and dispersion functions in the INJBT to the upper ring.

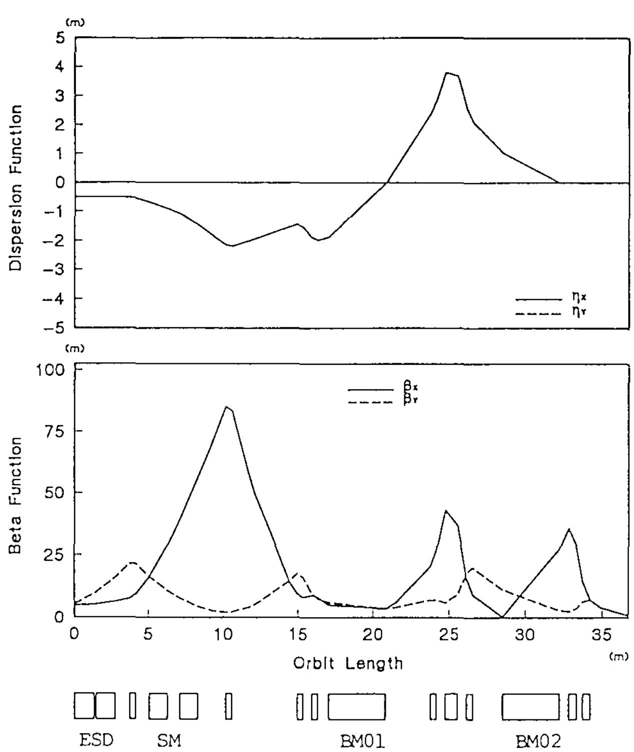

Fig. 3. Beta and dispersion functions in the EXBT.

On the other hand, The vertical beam line is designed to guide the beam from the upper ring and that from the lower one through a junction beam line. It can transport the beams up to 600 MeV/u to two treatment room (A,B) and a biological experiment room. It is possible for the same patient to be irradiated simultaneously by horizontal and vertical beam in the treatment room B. Further, the beam from the horizontal beam line can be guided to the vertical beam line by a switching magnet in the beam junction line. Therefore, the beams from the upper ring and the lower one can be transported alternately to the same target.

For achieving a required dose uniformity (±2%) in even the case of a broad beam (max. dia. of 220 mm) which is obtained by using scanner magnets and scatterer, the beam optics is designed such that the beam at each isocenter satisfies a doubly achromatic condition and is within the size of 10 mm. A typical calculation result is shown in Fig. 4. Further, this set of beam optics keeps the design acceptance of 10πmm mrad when the pole gap of all bending magnets are downsized to 60 mm for cost reduction.

In addition, the beam should be switched within 5 minutes from one course to the other by only adjusting the current of the switching magnet in order to obtain an efficient beam use for a treatment. The reproducibility of the beam position is required to be within ±2.5mm after beam switching. To satisfy the requirements, an excitation procedure of the magnet will be programmed for an initialization and setting the current, and its magnetic field will be precisely monitored by NMR. Further, a residual field of the switching magnet will be also compensated by using a small current source.

Beam profile monitors and steering magnets are assigned for the beam centroid displacement to be reduced within the size of 5 mm at a standard deviation. The beam profile monitor, which is a multiwire proportional chamber, was tested by using a proton beam of 70 MeV at NIRS and worked well in the intensity range corresponding to helium beams of 800 MeV/u at $1.4\text{x}10^{6}\sim1.4\text{x}10^{11}$.[5)]

The secondary beam line will be prepared for the study of diagnostic and therapeutic applications of a radioactive beam, which are separated from the primary and any other undesirable ions. Further, the momentum spread can be suppressed within ±0.2% by using a wedge degrader. The vertical beam line from the upper ring is also applicable for the same purposes. The produced radioactive beam is analyzed by four bending magnets and a slit, and is transported to the treatment room A or B. By using the radioactive beam, one can measure precisely the stopping point of the beam in a patient's body, and the treatment will be performed by using stable heavy ion beams with the same range as the radioactive beam.

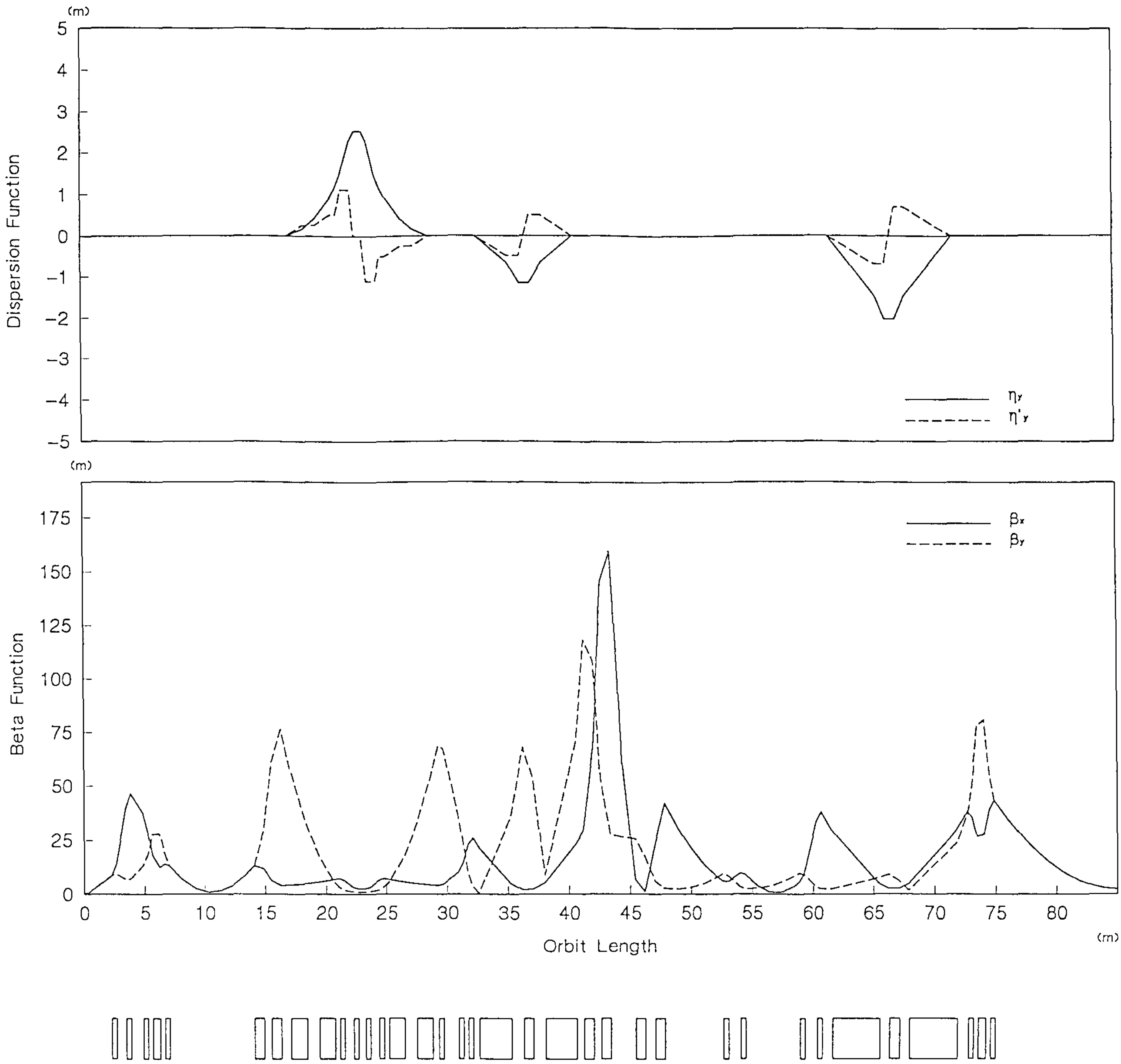

Fig. 4. Beta and dispersion function of the vertical beam line to the isocenter of the treatment room A.

5. Acknowledgment

The authors would like to express their sincere gratitude to Dr. K. Kawachi and the members of the Division of Accelerator Research of NIRS for their supports and helpful discussions. The authors also express thanks to the engineers of Toshiba Corp. and of Mitsubishi Electric Corp. for their useful assistance and discussion

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