BEAM DELIVERY SYSTEM OF HIMAC

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Abstract

The HIMAC (Heavy Ion Medical Accelerator in Chiba) is now under construction for cancer control at National Institute of Radiological Sciences (NIRS). The entire facility of the HIMAC will be completed in 1993 and the clinical treatment is expected to start in 1994. An outline and design considerations of high-energy beam delivery system are described.

Introduction

High radio-biological effectiveness and excellent dose localization are the advantages of high-energy heavy ions for cancer therapy. An accelerator complex, HIMAC[1,2], is now under construction at NIRS to realize radiotherapy utilizing the excellent characteristics of high-energy heavy ions for tumor treatments, diagnosis, fundamental research, and other biomedical applications. The HIMAC facility consists of an injector linac cascade[3], two synchrotron rings[4], a high-energy beam delivery system, a control system[5] and an irradiation system.

Requirements for the accelerator are summarized in Table 1., and requirements for radiotherapy are given in Table 2. Following items are taken into account for high-energy beam delivery system : 1) to provide horizontal and vertical beams, 2) to realize simultaneous irradiation by horizontal and vertical beams at different energies for the same patient or two different patients, 3) to switch beams from one treatment room to the other in a very short time. Independent horizontal and vertical beam transport lines will realize the second item of the requirement, which can be achieved only with two ring configuration.

Extracted beam transport lines

The synchrotron rings are placed on two stages seven meters apart. The slowly extracted beams from upper and lower rings are passed on independently to the high-energy beam delivery system through the upper or lower extracted beam transport line. The lower extracted beam transport line is shown in Fig.1. Each line consists of two 32.5° bending magnets and eight quadrupole magnets, and works as a matching section of beam parameters for the following line. Calculated parameters of beams at the end of the lines are,

$$\beta_x=1.0\mathrm{m},\quad \beta_y=1.0\mathrm{m},\quad \alpha_x=0,\quad \alpha_y=0$$

and dispersion free for both horizontal and vertical beam transport lines. Some elements for stopping beams, such as beam shutters, beam degraders and beam kickers, will be installed into the lines.

Vacuum pressure differences between the synchrotron rings and the extracted beam transport lines are compensated by differential pumping in the lines. Elements in these lines are controlled by a sub-control system for the synchrotron.

High Energy Beam lines

The high-energy beam delivery system consists of the vertical beam transport line which guides the beams from the upper synchrotron ring and the horizontal beam transport line which guides the beams from the lower one. Fig.2 shows a side view of the vertical beam transport line. Two treatment rooms on the 2nd basement and a biological irradiation room on the ground level are located in this line. A set of four 15° bending magnets and a set of two 30° bending magnets are used to transport the beams to the biological irradiation target on a horizontal line. To the treatment room B and the treatment room A, the beams are bended in the vertical direction through each pair of 45° bending magnets. The beams up to 600 MeV/u are transported in this line. A plane view of the horizontal beam transport line is shown in Fig.1. This line has two treatment rooms (B and C) and two experimental rooms, one for physics and general-purposes, and another for secondary beams. Magnetic rigidities of bending magnets in the line are 8.14 Tm and 9.73 Tm for the secondary beam line and the others, respectively. Simultaneous irradiation by horizontal and vertical beams for the same patient is possible in the treatment room B, as shown in Fig.1. A junction beam transport line is prepared to guide the horizontal beam into the vertical beam transport line. A switching magnet at the junction of this line is of a laminated structure,

Table 1.
Requirements for accelerator.

Particle species:	^{4}He to ^{40}Ar	
Maximum energy (MeV/u):	800 for q/A = 1/2	
Mimimun energy (MeV/u):	100	
Extracted beam intensity per ring (pps):	1.2×10^{10}	He
	2.0×10^{9}	C
	3.4×10^{9}	Ne
	4.5×10^{7}	Si
	2.7×10^{7}	Ar
Beam duration (ms):	400	
Repetition rate (Hz):	0.5 at 600 MeV/u	
Beam emittance (mm·mrad):	$\leqq 10\pi$	
Momentum spread (%):	$< \pm 0.2$	

Table 2.
Requirements for radiotherapy.

Field size (Max. dia. mm):	220				
Dose uniformity (%):	± 2				
Maximum range (mm):	300				
Particle species:	^{4}He	^{12}C	^{20}Ne	^{28}Si	^{40}Ar
Dose rate (at field size dia. 140 mm), (Gy/min)	5	5	5	0.5	0.5
(at field size dia. 220 mm) (Gy/min):	2	2	2.5	0.25	0.25
Intensity (at the target) (pps):	2.2×10^{9}	3.7×10^{8}	1.6×10^{8}	8.4×10^{6}	5.0×10^{6}

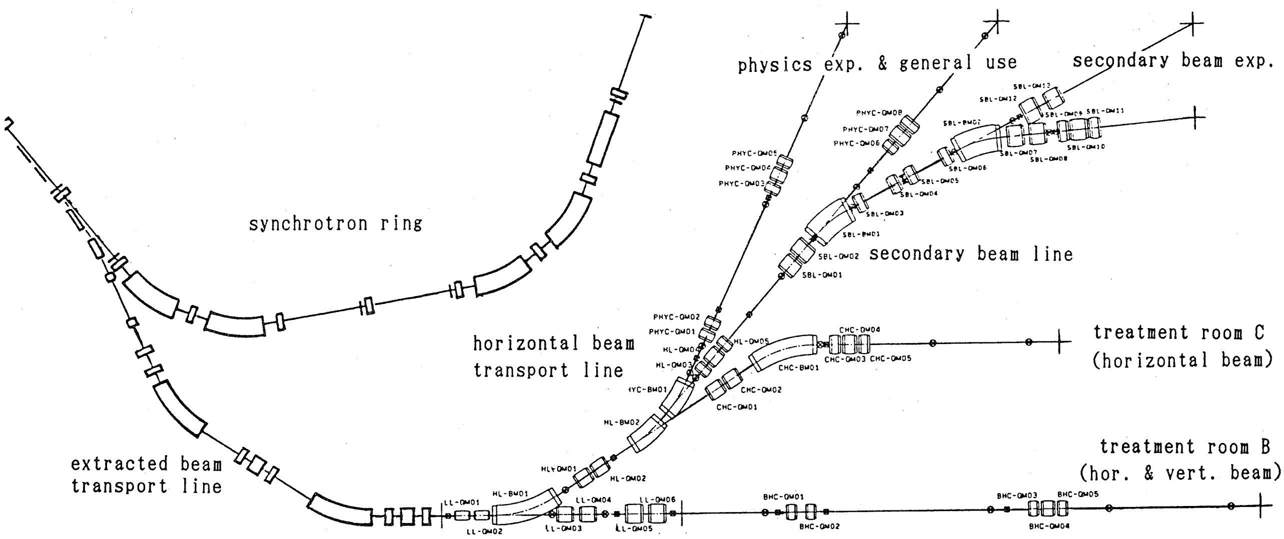

Fig. 1. A plan view of the extracted and the horizontal beam transport line.

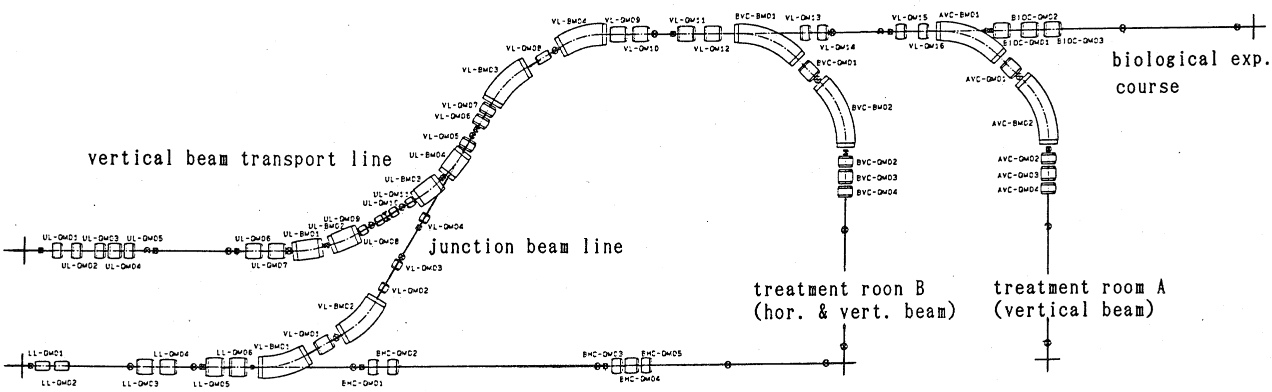

Fig. 2. A side view of the vertical beam transport line.

which is usable to join the both beams.

Beam optics studies have been made to satisty the requirements as follows.

1) Doubly achromatic beams with β function value within 2.5m is required at each isocenter.

2) Rapid beam switching from one treatment room to the other should be performed by only adjusting switching magnet current. No adjustment is required on focusing elements.

3) The pole gap of bending magnets should be within 60 mm for cost reduction.

Beta function of the vertical beam transport line to the isocenter of the treatment room B is given in Fig.3. To get an efficient beam use of treatment courses, it is necessary to change beams within 5 minutes from one course to the other, keeping the reproducibility of the beam position within ± 2.5 mm at the isocenter. Programmed excitation of magnets and precise monitoring of the magnetic field by an NMR field meter will be done. Correction coils and small current sources will be also prepared for compensating residual fields of the switching magnet.

Thirty-two beam profile monitors and forty magnetic steerers are distributed in beam lines. In order to guide beams with the orbit deviation within 5 mm from the reference orbit, a distribution of them has been investigated by evaluating the deviation due to alignment errors of magnetic elements.

A beam profile monitor is a multi-wire chamber which has 32 anode wires of 20 μm diameter with 2 mm spacing and anode-cathode distance of 4 mm. It will work for beam intensities in the range of 10^6 to 10^{11} pps.

Secondary beam line

Secondary beam line is provided for the development of diagnostic and therapeutic applications of radioactive beams.

A thick beryllium target will be placed in front of the first bending magnet of this line. The desired ions, for example ^{19}Ne or ^{10}C, are separated with analyzing magnets and slits from the primary and any other unwanted beams. A wedge degrader will be used for reducing the momentum spread. Resolution of the momentum analyzer is expected to be ± 0.2 % with a wedge degrader. The stopping position of radioactive beams in a patient's body is measured by a two dimensional positron camera. The vertical beam transport line from the upper synchrotron ring is also usable for the therapeutical applications of radioactive beams. A target will be placed in front of a set of four 15° bending magnets, which work as a momentum analyzer. The produced radioactive beams are transported to the treatment room B or A and are used for the precise stopping point measurement of the beams in a patient's body. The treatment will be carried out by heavy ion beams having the same range as the radioactive beams. The beams for treatment from the lower synchrotron ring can be guided to the same treatment room B or A, with the junction beam transport line.

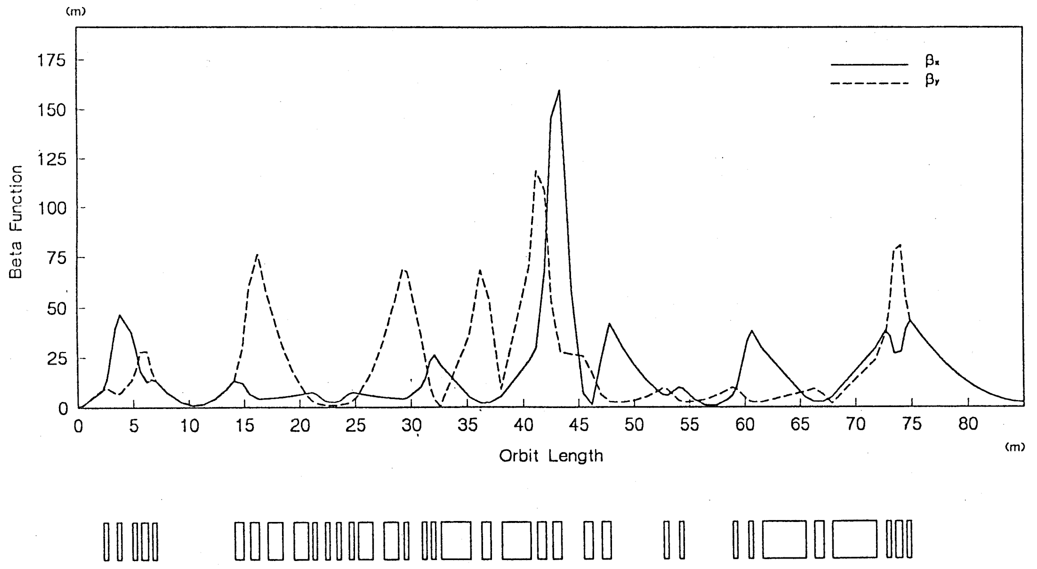

Fig. 3. Beta function of the vertical beam transport line to the iso-center of the treatment room B.

Treatment courses

As mentioned above, four treatment cources (two vertical and two horizontal beams) are prepared in three treatment rooms. One of the rooms (treatment room B) is installed with both courses for horizontal and vertical beams, and the other two (treatment room C or A) are installed with a course for horizontal or vertical beams respectively. A set of wobbler scanning magnets, a scatterer, a range shifter, a ridge filter, a multilief collimator and beam monitors, etc. are equipped in each course for controlling three-dimensional dose distribution[6]. These equipments are also installed in the biological experimental course. Precise irradiation dose control will be performed by cutting off a high voltage of an electrostatic deflector placed in the synchrotron ring for the slow beam extraction. Individual computer system is used to control all devices in the treatment rooms.

Control system

A HIMAC control system consists of a central computer and four sub-control systems including a control system of the high energy beam delivery system. A block diagram of the control system is shown in Fig.4. The control system is composed of a distributed processing system which links a master computer, a processing communicator and several remote I/O processing interfaces (RIO). Two consoles corresponding to the vertical beam transport line and the horizontal one are placed in the accelerator control room. The consoles work as man-machine interfaces through touch panels and rotary encoders. All devices are controlled through the RIO.

A timing signal synchronized to beam pulses is used for taking data from the beam profile monitors. The timing signals are generated as event signals on a sequence of synchrotron operation by a timing signal generator.

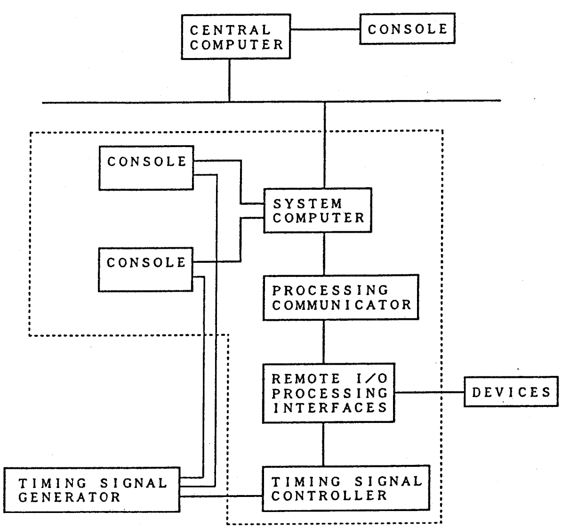

Fig. 4. Block diagram of the control system.

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