PERFORMANCE OF HIGH ENERGY BEAM TRANSPORT SYSTEM OF HEAVY ION MEDICAL ACCELERATOR, HIMAC

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Abstract

The high energy beam transport system consists of horizontal beam lines and vertical beam lines with total length of about 240m. The horizontal lines deliver beams extracted from a synchrotron ring installed on a lower level, and the vertical lines deliver beams from another synchrotron ring of an upper level. The beams are tuned with better than 1mm accuracy at isocenters so as to spread the beams to obtain spatially uniform beam for charged particle therapy. In the system, the beams are switched from one therapy room to another within 7 minutes by changing only current of switching magnets. Reproducibility of beam position is less than 1mm without tuning beams when the beam lines are switched. The beams of the horizontal and vertical lines can be independently tuned. A pulse magnet can merge the beams of both beam lines to make high duty factor heavy ion beams.

1 INTRODUCTION

The Heavy Ion Medical Accelerator in Chiba (HIMAC) is a complex of an injector linac cascade, two synchrotron rings, a high energy beam transport (HEBT) system and an irradiation system[1,2]. Slow charged particles with q/A=1/2 ~ 1/7 from ion sources are accelerated by the linac cascade consisted of an RFQ linac and an Alvarez linac up to 6MeV·A. The synchrotron rings accelerate particles with q/A=1/2 up to maximum 800MeV·A in repetition rate of 1/2 or 1/3 Hz. The beam of the particles is extracted in a slow extraction method with 11/3 resonance or in an RF knockout extraction[3], and is delivered through the high energy beam transport lines to therapy rooms in day time, and to experiment rooms in night time and a weekend.

The clinical trials were started in June, 1994. Until February 1996, 104 patients were treated with ^{12}C beams of 290, 350 and 400MeV·A. The tumor sites treated include a head and neck, a central nervous system, a lung, a tongue, a liver, a prostate and a uterine cervix.

There are three therapy rooms, A, B and C. The B room has a vertical and a horizontal beam ports. These rooms are arbitrarily used according to treatment plans. The beam must be supplied as soon as possible whenever a room becomes ready. This condition requires the beam transport system to switch the beam courses in 5 minutes or less. Beam energy is also changed according to a tumor. For the tumor deeply seated in a body or seated behind a pelvis, higher energy than 290MeV·A is necessary in order that particles have long ranges in the body or they penetrate the pelvis to reach the tumor behind it. It requires to change the energy and to deliver the beam in less than 1 hour. Hyogo Charged Particle Therapy Facility which will be started construction in 1996 requires 1 minute to switch the beam courses and 15 minutes or less to change the energy[4]. These times are critical factors to increase number of patients a day.

Three beam ports are supplied with the various beams for experiments. The beam condition depends on the experiments of biology, physics, materials, chemistry and so on. The HEBT system can widely treat with the various beams. In this paper the performance of the HEBT system of HIMAC is briefly reported.

2 LAYOUT OF THE HIGH ENERGY BEAM TRANSPORT LINES

The layout of the beam transport lines is shown in Figure 1. The beam lines are roughly separated into two groups of horizontal beam lines and vertical beam lines. The horizontal and vertical beam lines are connected with the lower synchrotron ring and the upper ring, respectively. A junction beam line connects both groups, and beams can be transported to the vertical lines from the lower ring. The vertical lines consist of two medical lines of therapy room A and B and one line for biology experiments. The horizontal lines consist of two medical lines of therapy room B and C and two lines used for general purposes. The constituents of the HEBT system are 16 bending magnets, 69 quadrupole magnets, 39 steering magnets, 35 beam monitors, 16 vacuum units, 3 sets of beam collimator and many other devices. The design of the optics has been reported[5].

Secondary beam lines branch from one of the beam lines for general purposes. They are under construction, and they will complete by the middle of 1998.

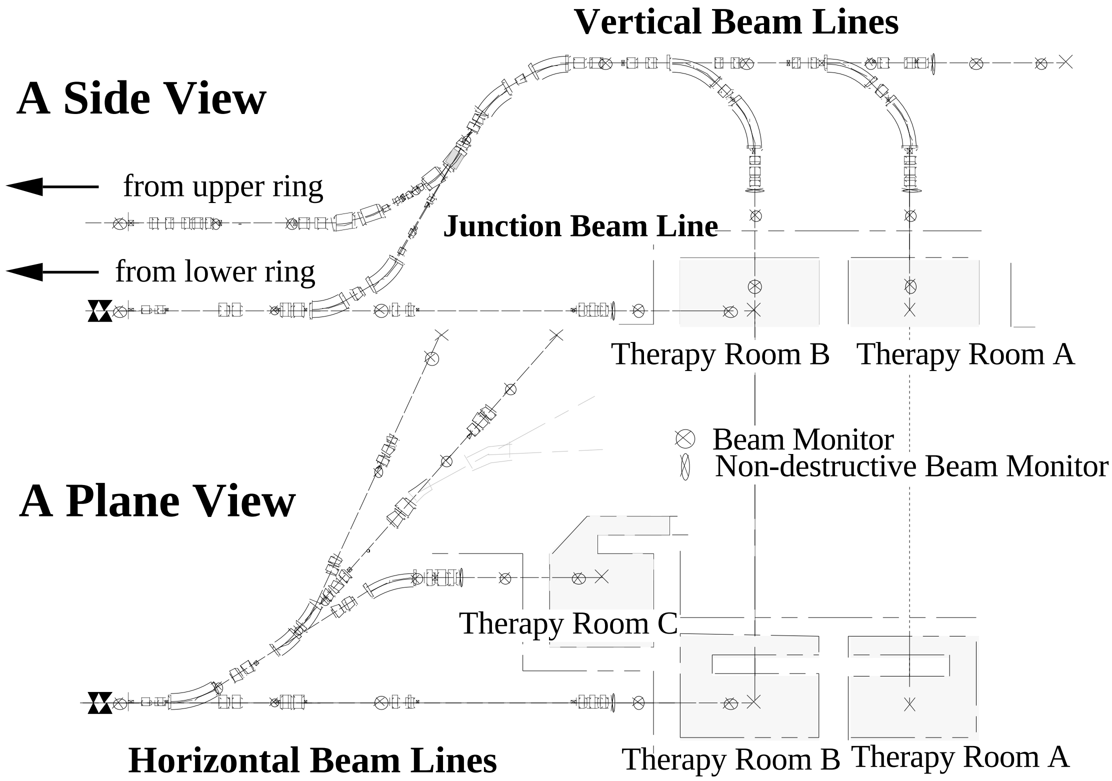

Figure: 1 The layout of the high energy beam transport lines, the therapy rooms and other experiment rooms.

3 BEAM TUNING

3.1 Daily tuning

The whole system of the beam lines is turned on for new beam condition with help of sequential operations by a computer and an interface system according to an operation parameter file (OPF) which includes setting values such as excitation currents of the magnets. In this operation, the magnets are initialized a few times before excitation to produce a proper magnetic field. Other devices, such as the beam monitors, automatically become ready by the operation. In about 5 minutes, all the devices are ready. The procedures are same for switching a beam course from one to another.

We defined a centroid of the beam profile to be the beam position. Operators adjust the beam positions on the center of the profile monitors within ±0.5mm along a beam line when they tune the beam. At the beginning of the day or for the new beam condition the beam is delivered to all the beam courses which are to be used for the treatments. It takes about 20 minutes.

There are 7 switching magnets located at points where a beam line branches or two beam lines merge. The beam courses can be easily switched in about 7 minutes by only adjusting currents of them. The beam can be delivered to the isocenter within ±1mm without beam tuning. Initializing the magnets is essential to reproduce the beam positions without beam tuning.

Beams are well reproduced unless the injection beam conditions vary, even if the synchrotron system or the HEBT system turns on repeatedly. Therefore well established OPF's of both systems can reproduce the beam condition without tuning the beam. The beam positions reproduce within ±1mm at the entrance of the therapy rooms. This situation makes the beam tuning time short drastically.

3.2 Auto beam tuning

Dose distribution on the patient is uniformed by circulating the beam with a pair of wobbler magnets. The distribution is not very sensitive to the beam profiles. But the beam position affects the distribution. Thus the beam for the treatment is delivered by using only steering magnets to steer the beam direction. We installed a software for automatically tuning the beam in order to shorten time of beam delivery, and to save number of operators. It controls only the steering magnets to deliver the beam to an isocenter in the therapy room with observing the beam positions. Excitation currents of the steering magnets can be calculated on the basis of actual beam positions at the monitors in a simple algorithm, because relations between displacement of the beam positions from the center of the monitors and variation of the excitation current of the magnets are well known. The auto beam tuning system is being adjusted for normal operation.

4 BEAM MONITORING

4.1 Beam monitoring system

There are 35 profile monitors. Each monitor was installed in a pair of a set of the steering magnets in principle. This configuration makes beam tuning easy and rapid. Ten monitors of them have an additional function for measurement of beam intensity. The monitors are fed with the mixture gas of Ar and CO_2(20%) for operation.

An MWPC as a sensor of the profile monitor has two orthogonal signal wire planes with the effective area of 64mm x 64mm. Each plane has 32 horizontal or vertical wires with 2mm spacing. The dynamic range of the monitor including electronics is magnitude of order of 7, so it can observe, for instance, the carbon beam at the intensity of 10^3pps to 10^9pps.

The beam intensity is measured by a plate parallel ion chamber. It was installed on back of the MWPC in a common vessel. The intensities measured by the monitor were agree within ±6% with those by an ionization chamber which was operated under atmospheric air, and those by a Faraday Cup. The beam intensity is shown in an unit of particle-per-pulse with the beam profiles on a display of a control room.

4.2 Continuous beam monitoring

The continuous beam monitoring is one of useful methods to ensure beam quality, such as beam intensity, profile and position, and synchronization of the beam extraction with a patient's respiration during the treatment for an organ moving with the respiration. The MWPC's, for these purposes, are also used in atmospheric air, and have no beam windows. The beam is scattered by only their wires. The effective thickness is approximately $8x10^{-2}g/cm^2$. It is corresponding to water equivalent thickness of 0.8mm, so it is negligibly small in comparison with a margin around a target volume in a body. Five monitors were installed in front of all the therapy rooms and the biology experiment room.

5 HIGH DUTY FACTOR HEAVY ION BEAMS

The beams are extracted every 2 or 3.3sec in duration of 0.2 ~ 1.5 sec. with a duty factor of 15% ~ 45%. Both beams extracted from the upper and lower rings can merge at the junction of the vertical beam line and the junction beam line with aid of a bending magnet excited in a pulse mode. It produces high duty factor beams of about 80% shown in Figure 2. Energy difference between both beams accelerated in the upper ring and the lower ring proved to be less than 0.05% in comparison of both ranges of the beams in water. The magnet can bend particles with q/A=1/2 of maximum 400MeV·A. The high duty factor beams take advantage of giving a high dose rate for the treatments with heavy charged particles like Si or Ar.

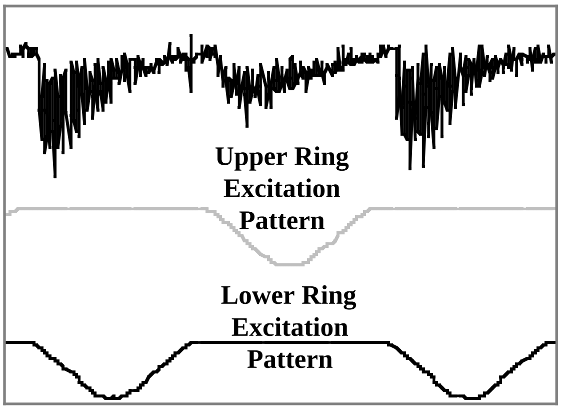

Figure: 2 Merged beam of ^{12}C 400MeV·A in 1/3Hz operation (upper). The duty factor was about 84%. Excitation patterns of both synchrotron rings are shown (middle and lower).

6 SUMMARY

The clinical situation basically requires that the beam is delivered as soon as possible, and reliably. It takes about 30 minutes to deliver the beam at the beginning and about 7 minutes to switch the beam course. The beam profile and intensity are easily monitored with the wide dynamic range at the same time. Continuous monitor of beam, especially, is useful to ensure beam condition during the treatments. The high duty factor beams have been realized for the future treatments of heavier particles.. The HEBT system totally works well and reliably, and is approaching to the clinical requirements.

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