NEW TREATMENT RESEARCH FACILITY PROJECT AT HIMAC

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Abstract

On the basis of more than ten-years of experience with HIMAC, we have proposed a new treatment facility for the further development of therapy with HIMAC. The new treatment research facility, as an extension of the existing one, has been designed, based on a 3D rescanning technique developed at NIRS. We report the related design and R&D works for the new treatment research facility at HIMAC.

INTRODUCTION

Heavy-ion beams are very suitable for the treatment of deeply seated cancer because of an excellent physical-dose distribution and high-LET characteristics around the Bragg peak. Therefore, NIRS decided to carry out heavy-ion cancer therapy with HIMAC [1]. The first clinical trial of cancer treatment with carbon beams was conducted in June 1994. The total number of patients treated until February 2010 was more than 5,000. On the basis of the more than ten year of experience with HIMAC, we have proposed a new treatment research facility toward adaptive cancer therapy [2] with heavy ions, making the one-day treatment of lung cancer possible. Further, the new treatment research facility should accurately treat a fixed target, a moving target with breathing and/or a target near a critical organ. For these purposes, a 3D rescanning method with a pencil beam [3] is employed. A rotating gantry with the 3D rescanning method [4] is also employed. The design study and the related R&D work have been carried out with HIMAC since 2006. A construction of the facility building was completed in March 2010. After installing and tuning up the devices, the first patient will be treated in March 2011.

DESIGN CONSIDERATION

Specification

A main specification such as ion species and irradiation-field size in the new treatment research facility [5] was determined by using the clinical statistics for the more than ten-year treatment period at HIMAC, as summarized in Table 1.

Table 1: Main Specification

Ion Species	^{12}C, ^{16}O, ^{11}C, ^{15}O	
	Fixed Port	Rotating Gantry
Energy	140-430 MeV/n	140-400 MeV/n
Lateral Field	22cm×22cm	15cm×15cm
SOBP	15 cm	15 cm

The maximum ion energy is designed to be 430 MeV/n in the fixed beam-delivery system, which brings the residual range of 30 cm in a ^{12}C beam and that of 22 cm in an ^{16}O beam. On the other hand, the rotating gantry system employs the maximum energy of 400 MeV/n and the smaller lateral-field size of 15 cm × 15 cm in order to downsize the gantry size. Further, positron-emission beams, such as ^{11}C and ^{15}O, will be used to verify the irradiation area and their ranges in a patient's body. The R&D work has been carried out in order to obtain positron-emission beams accelerated directly through the HIMAC accelerator [6], instead of using the projectile-fragmentation method.

Irradiation Method

In HIMAC treatments, sometimes, we have observed shrinkage of the target size and a change of its shape during the entire treatment. In order to keep the sophisticated conformations of the dose distributions even in such cases, it has been required that treatment planning is carried out just before each fractional irradiation, which we call adaptive therapy. The new facility should employ a pencil-beam scanning method for a fixed target, a moving target and/or a target near critical organs, toward the target of the implementation of adaptive cancer therapy. It is also well-known that 3D scanning has brought about a highly treatment accuracy in the case of a fixed target. However, this method has not yet been applied to treating a moving target with breathing in practical use. Therefore, we have developed a phase-controlled rescanning (PCR) method [3] with a pencil-beam, especially for treatment of moving target. In the PCR method, rescanning completes the irradiation of one slice during a single gated period corresponding to the phase between the end of expiration and the beginning of inspiration, because the organs are most stable during this gated period. Further, since the average displacement of the target over a single gated period is close to "zero", we can obtain uniform dose distribution

even under irradiation of a moving target. The PCR method requires mainly two technologies: (1) intensity-modulation technique for a constant irradiation time on each slice having a different cross-section and (2) fast pencil-beam scanning technique for completing several-times rescanning within a tolerable time.

Facility Planning

The new treatment research facility is connected with the upper synchrotron at HIMAC. In the treatment hall, placed underground of the facility, three treatment rooms are prepared in order to treat more than 800 patients per year. Two of them are equipped with fixed beam-delivery systems in both the horizontal and vertical directions, and the other is equipped with a rotating gantry. Two treatment-simulation rooms are also prepared for patient positioning as a rehearsal, and for observing any change of the target size and shape with X-ray CT during the entire treatment. Further, six rooms are devoted to patient preparation before irradiation. Schematic views of the new treatment facility and the treatment hall are shown in Fig. 1.
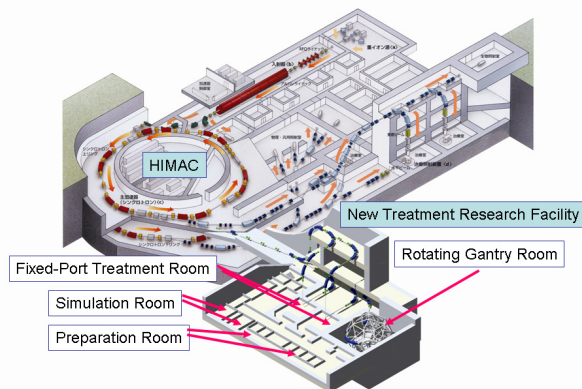

Figure 1: Schematic view of the new treatment facility.

DESIGN AND R&D STUDIES

Design of BT and Beam-delivery System

In the new treatment research facility, beam transport (BT) lines are designed to make energy scan [7] possible. Thus all of the magnets will be manufactured with laminated iron plates. The beam optics is designed to realize dispersion free in the fixed beam-delivery system, and the beam size can be changed from 2 to 8 mm at one-sigma by using the final Q-triplet. The beam-position changes due to undesirable parameter change of the synchrotron, which can be corrected by using a pair of steering magnets and non-destructive screen monitors in both horizontal and vertical directions in the beam-delivery system.

The fixed beam-delivery system is designed to realize the PCR method with the fast raster scanning and to be same configuration in both the horizontal and vertical directions. The system consists of a pair of scanning magnets, dose monitors, a ridge filter and a range shifter. The total length of the system is around 9 m. The beam-scanning speed is designed to be 100 mm/ms for fast scanning. Two dose monitors, which are parallel-plate ionization chambers with an effective area of 250 mm^2, are used for dose management. The beam position and size are monitored by multi-wire proportional counters. Considering the slice thickness, the Bragg peak is slightly spread out by a mini ridge filter. The range shifter is utilized to change the slice in the target. Thus, the range shifter should be as close as possible to the iso-center in order to avoid any change of the beam size by multiple scattering through the range shifter.

In the design of the rotating gantry, the final dipole magnet is divided into 30-degree and 60-degree magnets, and two scanners are placed between the two dipole magnets in order to extend the effective length from the scanners to the iso-center, which can downsize the gantry. The total weight of the rotating-gantry system is around 350 tons. In order to avoid any change of the beam size depending on the rotation angle, further, we will adapt a compensation method of the asymmetric phase-space distribution [8].

Intensity Modulation

We have developed a spill control system [9] in order to deliver the beam with intensity modulation, based on improvement of the RF-KO slow extraction method. The core part of this system requires the following functions: (1) calculation and output of an AM signal according to request-signals from an irradiation system, (2) real-time processing with a time resolution less than 1 ms, and (3) feed-forward and feedback controls to realize the extracted intensity as requested. This system allows us to dynamically control the beam intensity almost as required, as shown in Fig. 2.
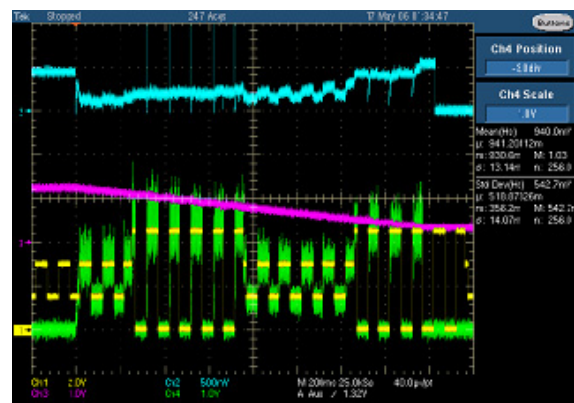

Figure 2: Intensity modulation by spill control system.

Intensity Upgrade and Extended Flat-top Operation

The beam intensity extracted from the synchrotron has been increased in order to complete single-fractional irradiation with one operation cycle. In this case, the efficiency of the gated irradiation will be increased by a factor of about 2, because we can extend the flattop infinitely in principle. The extended flattop operation will save considerably irradiation time. In order to increase the beam intensity, we have thus developed a correction method of the third-order resonance that causes the strong beam loss just after a beam injection into the synchrotron. In addition, the multi-harmonics operation of the RF acceleration system can also increase the intensity, because of suppressing the space-charge effect after bunching. Consequently, around 2×10^{10} carbon ions can be accelerated to the final energy. This intensity is sufficiently high to complete single-fractional irradiation for almost all tumours treated with HIMAC when using the 3D-scanning method with beam-utilization efficiency more than 90%. The extended flattop operation was successfully tested at the HIMAC synchrotron, as shown in Fig. 3.
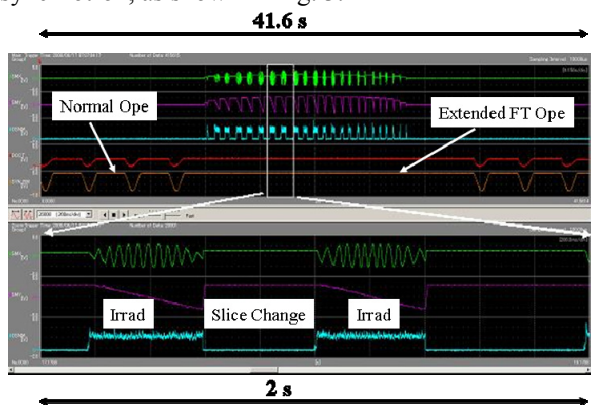

Figure 3: Extended flattop operation of the HIMAC synchrotron.

Fast raster-scanning experiment

We designed and constructed a test irradiation port for the fast raster-scanning experiment in order to verify the design goal, which was the same configuration as the fixed beam-delivery system adapted to the new treatment research facility. The test irradiation port is shown in Fig. 4. We have adapted the measured dose response of the pencil beam with various energies. The beam size at the entrance and the width of the Gaussian-shaped mini-peak were 3.5 and 4 mm at one standard deviation, respectively. As a result of the experiment, the validity of the beam model and the optimization calculation had already been verified [10, 11]. In the experiment, further, we obtained a uniform physical dose field not only for a fixed target, but also for a moving one. Owing to the extra-dose prediction method taken account into the new

treatment planning, the extended flattop operation and the fast scanning system, the irradiation time was significantly shortened by around 100 times compared with that of the conventional spot scanning. The experimental result is described in the Ref [12].

SUMMARY

During the more than ten-year of clinical trials with HIMAC, both the beam-delivery and the accelerator technologies have been significantly improved. It has brought the good result of the clinical trial. Therefore we proposed the new treatment facility project for further development of the HIMAC treatment. In this project, a patient positioning system, treatment planning system for the PCR method and Carbon-RT information system have been developed as well as that of the accelerator and beam delivery systems since April 2006. At December 2007, the Japanese government approved this project. The facility building was already completed in March 2010, and the first patient will be treated in the next March
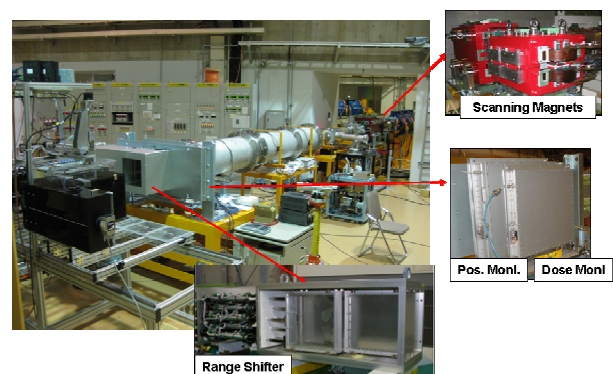

Figure 4: Fast 3D-rescanning test port installed in the HIMAC facility.

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