DEVELOPMENT FOR NEW CARBON CANCER-THERAPY FACILITY AND FUTURE PLAN OF HIMAC

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Abstract

The new carbon-therapy facility has been constructed at Gunma University since April 2006, based on the design study and R&D works at HIMAC. As a future plan for the HIMAC, further, a new treatment facility was initiated at NIRS from April 2006.

INTRODUCTION

Since the first clinical trial on three patients with HIMAC [1] in June 1994, total number of treated patients exceeded 2,600 in this March. As a result of accumulating numbers of protocols, the carbon therapy at NIRS was approved as a highly advanced medical therapy by the Japanese government. Based on the development and experiences of more than ten years at HIMAC, we proposed a compact carbon-therapy facility, which was initiated in this April at Gunma University. In this facility, a compact accelerator complex will deliver carbon beams with the energy range from 140 to 400 MeV/n to three treatment rooms. As a future plan of HIMAC, further, a new treatment-facility project was initiated in this April. This facility, which will be connected with the HIMAC accelerator, consists of three treatment rooms; two rooms equipped with the horizontal and vertical scanning-irradiation ports and another room with a rotating gantry. The design studies and R&D works for these projects are reported in this paper.

NEW CARBON-THERAPY FACILITY

Design Considerations and Specifications

In order to treat more than 600 patients per year due to an economical reason, the facility requires three treatment rooms; (H-port), (V-port) and (H&V-port) where are placed at the same floor.

Both of the irradiation gated with patient's respiration [2] and the layer-stacking irradiation method [3, 4] are required to sufficiently suppress undesirable dose.

Considering a result of treatments at HIMAC, it is found that the residual range requires 250 mm. Further the irradiation-filed diameter of 220 mm and the SOBP size of 150 mm cover treatments of more than 97% and of more than 95%, respectively. The residual range depends not only on the beam energy, but also on the irradiation method. Using the spiral-wobbler [5] and raster scanning methods, the carbon energy is estimated to be 400 MeV/n in order to obtain the residual range of 250 mm. For the treatment for eye melanoma, on the other hand, the minimum energy is to be 140 MeV/n. Further the required beam intensity is estimated to be $1.2\cdot10^9$ pps to deliver the dose rate of 5 GyE/min/*l*, under the beam-utilization efficiency of 40%. The specifications are summarized at Table 1.

Table 1: Specifications of a new carbon-therapy facility

Ion Species	Carbon
Energy	400 – 140 MeV/n
Range/SOBP/Lateral-Size	250/40-150/220mm
Max. Dose Rate	5 GyE/min/*l*
Beam Intensity	$1.2\cdot10^9$ pps
Treatment Room	3: H&V, H, V
Irradiation Method	Gating/Layer Stacking

Design Study and R&D Works

Beam Delivery System

A beam-delivery system was designed so as to obtain a residual range of 250 mm under the carbon energy of 400 MeV/n and an irradiation-field radius of 220 mm. The layout of the system is shown in Fig. 1. This system consists of dose monitors, scanning magnets, a scatterer, a ridge filter, a range shifter and collimators. The ridge filter is designed to change the SOBP size from 40 to 150 mm. The range shifter is installed to adjust preciously the residual range in a patient. The multi-leaf and bolus collimators define preciously the lateral irradiation field and the distal one, respectively. Since the multi-leaf collimator employs thin leaves with the thickness of less than 3 mm, a patient collimator is not requires.

Both of the spiral-wobbler and raster scanning methods have been studied in a test-bench. As shown in Fig. 2, it was verified that both methods could produce an

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irradiation field within the uniformity of ±2.5%, under using thin scatterer and small beam size compared with those used in the conventional wobbler method. Further, both methods can easily realize the irradiation gated with respiration and the layer-stack irradiation, because only the total dose should be managed. The raster scanning method has flexibility for various target shapes, compared with the spiral-wobbler one.

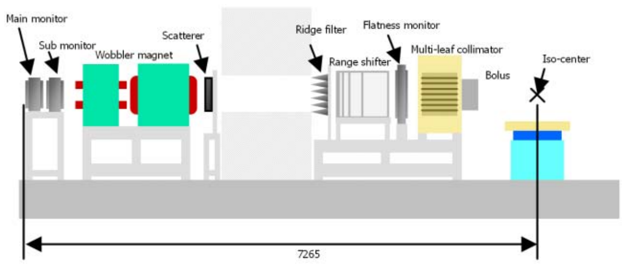

Figure 1: Layout of the beam delivery system.

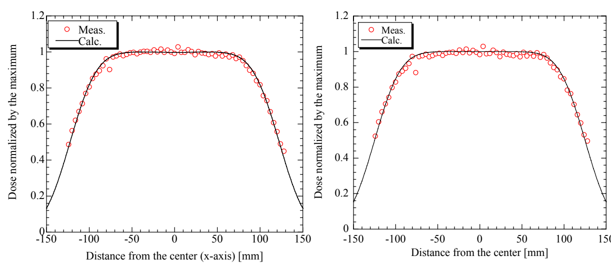

Figure 2: Lateral dose distribution by spiral wobbler (left) and raster scanning (right) after 1 min irradiation. Circles are measured dose distribution and solid line designed one.

Injector System for Synchrotron

The compact injector system consists of a compact 10 GHz-ECR ion source [6] and a linac cascade; An RFQ linac and an Alternating-Phase-Focused (APF) IH linac with the same operating frequency of 200 MHz. The output energy of the injector cascade is designed to be 4.0 MeV/n. The required intensity is 200 eμA in C^{6+} after a charge stripper.

Based on the electric-field measurement of the model cavity [7], the high-power cavity of the APF-IH linac was designed and manufactured, and was installed in conjunction with the ECR ion source and the RFQ linac. After the installation shown in Fig. 3, beam acceleration tests have been carried out [8]. C^{4+} ions extracted from the RFQ linac were injected to the APF-IH linac and successfully accelerated up to 4.0 MeV/n. The centre energy and the energy spread were 4.0 MeV/n and ±0.4%, respectively, which were in good agreement with the design values. The intensity of C^{4+} from the APF-IH linac was measured to be 380 eμA corresponding to 570 eμA in C^{6+}, which is enough high compared with the requirement even under a stripping efficiency of 90%.

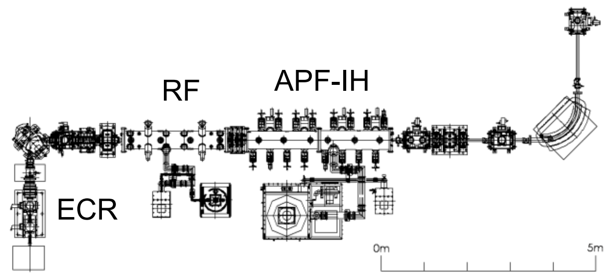

Figure 3: A test bench for the compact injector system.

Synchrotron

The synchrotron is designed to accelerate C^{6+} beam from 4 to 400 MeV/n. The injection and slow-extraction systems employ the multi-turn injection for increase of intensity and the RF-KO extraction method [9] for the irradiation gated with respiration, respectively. A layout of the synchrotron is shown in Fig. 4. In order to downsize the synchrotron, the lattice structure employs a FODO missing magnet design, while each cell contains three dipole magnets and two kinds of quadrupole magnets (QF/QD). As a result, the ring circumference is considerably reduced to be 61.5 m. The design study and R&D works for the synchrotron and high-energy beam transport systems are described in detail in Ref. [10, 11].

An un-tuned RF-cavity, having a Co-based magnetic-alloy core, has been developed [12, 13] so as to make multi-harmonics operation possible for reducing the longitudinal space-charge effect. This RF-cavity was installed in the HIMAC synchrotron, and a beam test was successfully carried out.

In the gated irradiation, a part of an accelerated beam is frequently remained, which produces a large amount of neutrons. The new facility as well as HIMAC employ, thus, to decelerate the remained beam to the injection-energy level, which can reduce a radiation-shielding wall. As a result, the facility-building cost can be considerably reduced.

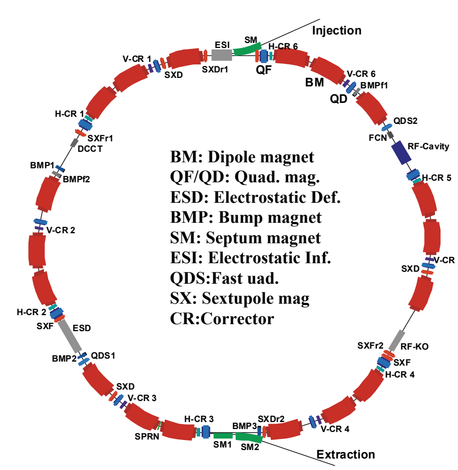

Figure 4: Layout of synchrotron.

Layout of New Carbon-Therapy Facility

A layout of the new carbon-therapy facility for Gunma University is shown in Fig. 5. The facility size, including a fourth room for development of a new irradiation method, diagnosis rooms, lobby, staff rooms and control room, is designed to be 66 m × 50 m × 24 m, and it is around one-third compared with that of HIMAC.

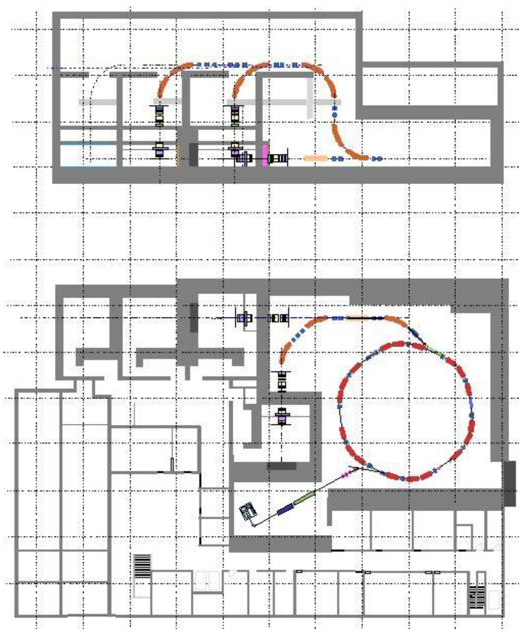

Figure 5: Layout of new carbon-therapy facility at Gunma University.

NEW TREATMENT FACILITY

Design study on a new treatment facility with HIMAC has just been initiated with a view to the further development of the carbon-ion therapy. The new facility is connected with the HIMAC accelerator complex and has three treatment rooms. Two of them are equipped with both horizontal and vertical beam-delivery systems and the another one is equipped with a rotating gantry. The schematic view of the new facility with the HIMAC is shown in Fig. 6.

In the new facility, repainting method with a beam-scanning in the respiration-gated irradiation has been chosen to achieve high accuracy in the treatment of tumours moving with breathing. In the treatment of a head and neck tumour, on the other hand, the spot scanning will be applied for high accurate treatment. The irradiation-field size is required to be same as the HIMAC treatment, and the carbon-beam energy is 430 MeV/n at maximum. At present, the spot-scanning method has been studied with the intensity and spill controls [14].

The rotating gantry has been conceptually designed so as to permit easily "on-demand treatment" such as one-day treatment for a lung cancer. At the present design of the gantry, the specifications are as follows: the maximum beam energy is 400 MeV/n, the lateral field is 150 mm × 150 mm in square, the SOBP size and the residual range are 150 mm and 250 mm at maximum, respectively. In order to downsize the gantry, a final dipole magnet is utilized as one of the scanning magnets. As a result, its weight is around 300 ton.

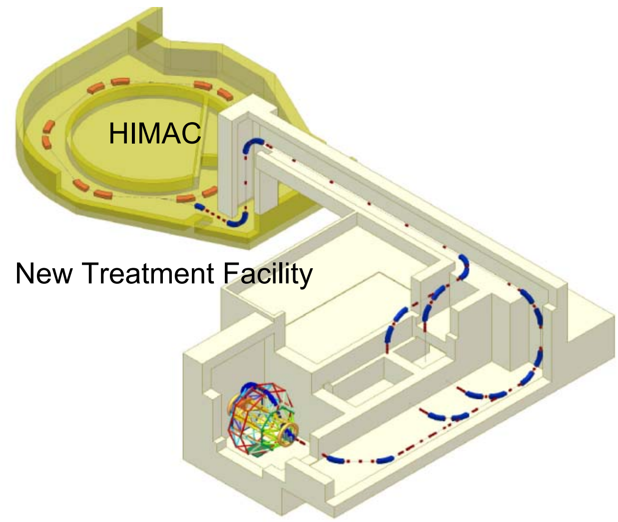

Figure 6: Schematic view of new therapy facility at HIMAC.

SUMMARY

During more than ten-years 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 and resulted in rapidly growing interest in the carbon therapy. Nowadays, there are several candidates for the carbon therapy in Japan. Therefore, NIRS has proposed a carbon-beam facility for cancer therapy. One of candidates, Gunma University, was approved to construct a new carbon-therapy facility by the government, and was initiated from this April, based on NIRS proposal. At the same time, a new treatment facility with HIMAC was initiated at NIRS.

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