UPDATE OF AN ACCELERATOR CONTROL SYSTEM FOR THE NEW TREATMENT FACILITY AT HIMAC

Y. Iwata*, T. Furukawa, K. Noda, T. Shirai, E. Takada,
National Institute of Radiological Sciences (NIRS), 4-9-1 Anagawa, Inage, Chiba 263-8555, Japan.
T. Kadowaki, Y. Sano, and H. Uchiyama,
Accelerator Engineering Corporation (AEC), 2-12-1 Konakadai, Inage, Chiba 263-8555, Japan.

Abstract

The control scheme of the HIMAC accelerators has been developed for the new treatment facility, which will be constructed adjacent to the existing HIMAC accelerator complex. The new treatment facility will have three treatment rooms, where a raster-scanning irradiation will be performed. To fulfil requirements of the scanning irradiation, we are developing a control scheme for a multiple-level-flattop operation. With this control, the beam energy can be continuously varied within a single synchrotron cycle. Successful results of beam acceleration and extraction tests proved the feasibility of the multiple-energy operation.

INTRODUCTION

Tumour therapy using energetic carbon ions, as provided by the Heavy-Ion Medical Accelerator in Chiba (HIMAC) at the National Institute of Radiological Sciences (NIRS), has been performed since June 1994[1], and approximately 4,000 patients were treated until now. With the successful clinical results over more than ten years, we started to construct a new treatment facility at the NIRS[2].

The new treatment facility will have three treatment rooms; two of them have both horizontal and vertical fixed-irradiation-ports, and the other would be a rotating gantry-port[3]. For all the ports, a raster-scanning irradiation method will be applied[4]. The new facility will be constructed adjacent to the HIMAC accelerator complex. A high-energy beam-transport (HEBT) line of the new facility would be connected to the synchrotron ring of the HIMAC, and heavy-ion beams will be provided by the existing accelerators. In the new facility, laminated magnets will be used for all the transport line to minimize the switching time of the beam course as well as to vary the beam energy quickly, as will be discussed in the following section.

To fulfil requirements of the raster-scanning irradiation, which would be performed in the new facility, we are updating the control system of the HIMAC accelerator. The proposed control system would enable us to provide heavy ions having variable energies within a single synchrotron-cycle; namely, the beam energy would be changed a few tenth of times successively within a single synchrotron-pulse by an energy step, corresponding to a water range of approximately 2 mm. Since the beam range would be controlled without using energy degraders, an excellent irradiation field could be obtained. In this paper, the update of the control system of the HIMAC accelerator for the new treatment facility is presented.

UPDATE OF ACCELERATOR CONTROL SYSTEM

Quasi-DC Extension of Flattop

As mentioned previously, heavy-ion beams for the three treatment rooms in the new facility are provided by the upper synchrotron-ring in the existing HIMAC accelerator. In the present operation of the synchrotron, one cycle of a beam injection, acceleration and extraction is made every 3.3 s. Within the cycle, the beam would be extracted and irradiated to a patient during approximately 2 s on the flattop of a synchrotron pattern.

Because the heavy-ion therapy provides excellent dose localization on a target as compared with conventional radiation therapy, a motion of the target as caused by respiration of a patient is a concern. For the moving targets, such as liver and lung cancers, a respiration-gated irradiation was developed[5], and will also be used for the raster-scanning irradiation. A timing chart of the respiration-gated irradiation is presented in Figure 1. Respiration of a patient is monitored, and converted to an electric signal. A respiration gate is made open if the amplitude of the electric respiration signal is below a certain threshold. Beam extraction, as controlled by the RF-KO extraction[6], is gated with the signal of the respiration gate, such that the target is irradiated during certain respiration phases, and hence the target position to be irradiated can be localized.

For the present operation of the synchrotron, inevitable dead-time exists in the respiration-gated irradiation, because the synchrotron requires certain time for injection and acceleration, and cycle of the synchrotron is fixed, as schematically described in Figure 1. This dead-time would make the total irradiation time longer.

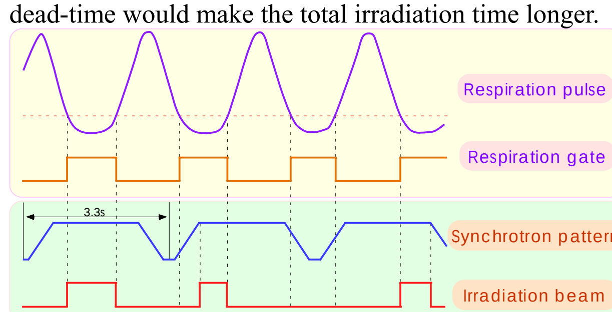

Figure 1: A timing chart of a respiration-gated irradiation.

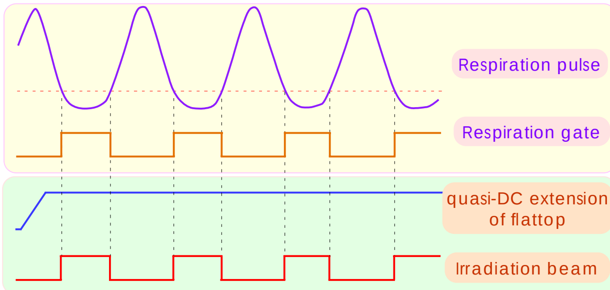

Figure 2: A timing chart of a respiration-gated irradiation using the quasi-DC extension of the flattop operation.

To overcome this problem, we developed the quasi-DC extension of flattop. As given in Figure 2, the flattop of the synchrotron pattern is extended, and the beam is extracted by using the RF-KO extraction during the respiration gate is opened; this operation would improve the dead-time of the irradiation.

This operation will be also applied to the raster-scanning irradiation in the new facility. The raster-scanning irradiation enables us to irradiate more than 90% of the beam particles on the target. Since the synchrotron ring of the HIMAC can accelerate a few $\times 10^{10}$ of carbon ions within one synchrotron cycle, and numbers of carbon ions as required to treat a typical size of tumours are an order of 10^{9} particles, most of the treatments can be completed within a single synchrotron cycle, provided that most of the accelerated particles are actually utilized in treatment dose. Consequently, having applied the quasi-DC extension of the flattop to the raster-scanning irradiation, the total irradiation time is considerably decreased down to a few seconds. The quasi-DC extension of the flattop was successfully tested and implemented in the HIMAC accelerator control.

Multiple-Energy Operation –Scheme–

To control the depth dose-distribution, a range shifter, consisting of PMMA plates having various thicknesses, is used as energy degraders of carbon ions as shown in Figure 3. With the range shifter, a range of the beam can be varied by a typical step-size of 2 mm. Since the focused beam as provided by the accelerator is used in the raster-scanning irradiation, this range shifter may broaden the spot size of the beam on the target. Therefore, it is preferable to change the beam energy directly by the accelerators within a synchrotron cycle.

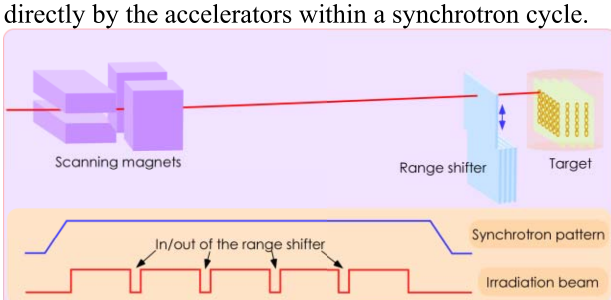

Figure 3: A schematic drawing of the quasi-DC extension of the flattop operation with a range shifter.

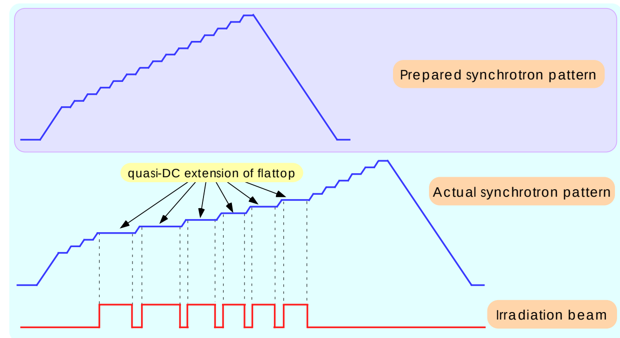

Figure 4: A schematic drawing of the synchrotron patterns for the multiple-energy operation with the quasi-DC extension of the flattop. The stepwise patterns show the current pattern of the main bending and quadrupole magnet of the synchrotron ring.

To change the beam energy, we propose the multiple-energy operation with the quasi-DC extension of the flattop. A schematic drawing of a single synchrotron cycle for this control is presented in Figure 4. The stepwise pattern on the top of the figure shows the current pattern of the main bending or quadrupole magnets in the synchrotron ring. The difference of the currents between the neighbouring steps is designed to provide the difference in a range of 2 mm in water. This pattern would be initially loaded to power supplies of the magnets. Once a patient to be treated is determined, a treatment planning and irradiation control system would provide a list of required energies to the control system of the accelerator. As the treatment starts, the stepwise pattern would be latched at the flattop of the corresponding energy, as requested by the irradiation control system, and the quasi-DC extension of the flattop operation initiates as presented in Figure 4. Once the required dose is irradiated to the corresponding depth, the beam is then turned off, using the RF-KO, and reaccelerated to the next requested energy. By using the variable-energy control with the quasi-DC extension of the flattop, the beam energy can be continuously varied directly by the accelerators, and hence no energy degrader is required.

Although the HIMAC accelerator can accelerate a sufficient number of carbon ions to complete a single treatment just with one synchrotron pulse, as mentioned previously, lack of the beam ions may occur in a treatment of a tumour having large volume.

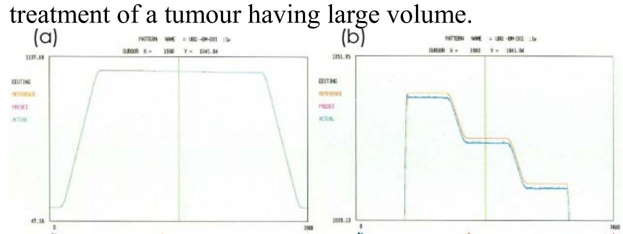

Figure 5: (a) A prepared current pattern of the main bending magnets for the synchrotron ring, as used in the acceleration tests. (b) A blow-up of the current pattern around the flattop region.

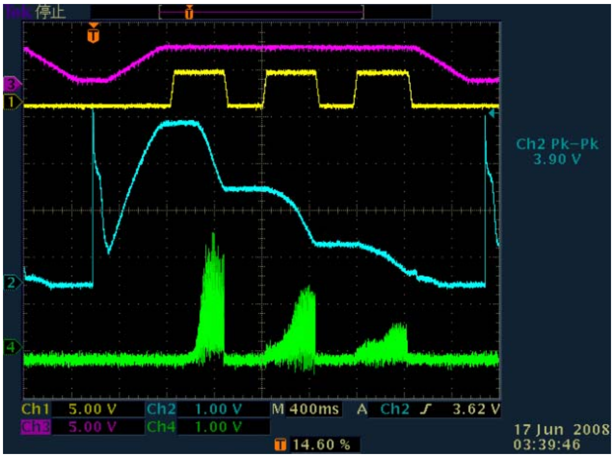

Figure 6: A snap shot of the oscilloscope during the beam acceleration and extraction tests (see text).

During the treatment, the beam current in the ring is always monitored by using the DCCT, installed in the ring. Once the lack of the beam current is detected, the control system of the accelerator would turn the beam off, and try to inject beam ions from the injector without performing the quasi-DC extension of the flattop operation. After the injection, the beam would be accelerated to the energy, at which the lack of the beam current was detected, and then the treatment will be resumed.

–Beam test–

To prove the feasibility of the variable-energy control, beam extraction tests were performed using the upper synchrotron ring of the HIMAC. Figure 5 shows a prepared current pattern of the main bending magnet. The currents of the first, second and third flattops correspond to the beam energies of 290.0, 287.1 and 284.2 MeV/u, respectively. Figure 6 shows a snap shot of the oscilloscope during the tests. The purple and yellow lines show current patterns of the main bending and sextupole magnets in the ring, respectively. The blue line indicates the beam current in the ring, as monitored with the DCCT, installed in the ring. The green line shows the measured beam-intensity of the extracted beam. We can see from the figure that the beam ions were successfully extracted at the respective energies.

The extracted beams having the three different energies were measured with a screen monitor, located at a few meter downstream of the extraction point. Pictures of the screen monitor are provided in Figure 7. Since the magnetic field of the septum magnets at the extraction channel was fixed to see the difference of the beam energies in the monitor, the three spots on the different positions of the monitor, corresponding to the difference in the beam energies, are clearly observed. These successful results of the acceleration and extraction tests indicate the feasibility of the multiple-energy operation with the quasi-DC extension of the flattop. We will further develop the control system of the HIMAC accelerator for the upcoming treatment facility.

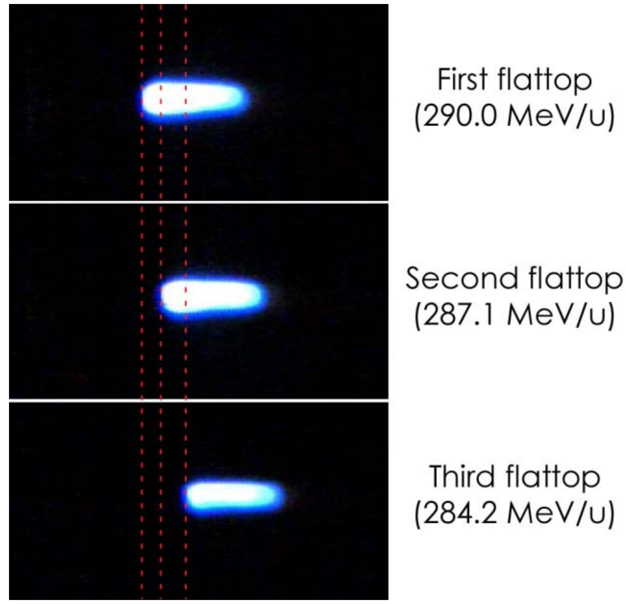

Figure 7: Pictures of a screen monitor. Three beam spots, corresponding to the respective beam energies, are clearly observed.

SUMMARY

We are updating the control system of the HIMAC accelerators for the new treatment facility, which has been constructed adjacent to the HIMAC. With the quasi-DC extension of the flattop operation, the synchrotron ring can provide a *DC-like* beam during a treatment, making the treatment time shorter, particular for the respiration-gated irradiations. Since our ring can accelerate a sufficient number of carbon ions, a treatment can be made just with a single extended-cycle of the synchrotron.

Furthermore, the multiple-energy operation with the quasi-DC extension of the flattop is proposed. With this control, the beam energy can be successively varied within a single synchrotron-cycle, and therefore no energy degrader or the range shifter is required. The beam acceleration and extraction tests of the multiple-energy operation were successfully made. We will further develop the control system for the new treatment facility.

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* Corresponding author. E-mail: y_iwata@nirs.go.jp

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