SCANNING IRRADIATION SYSTEM AT SAGA-HIMAT

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Abstract

At SAGA-HIMAT, 651 patients have been treated by use of two irradiation rooms in 2016 financial year. To increase treatment capacity of our facility, we have started the construction of the third treatment room C with a scanning irradiation system at the beginning of 2014. This construction was required to carry out without interruption on the treatments in room A and room B. With this requirement, installations of the beam line and irradiation devices have been done in the night time and weak end, and beam tests were also. Test irradiations have been started in the beginning of 2016, and the scanning system is almost ready for treatment now. In this paper, we will present current performances of our scanning system.

INTRODUCTION

Carbon ion radiotherapy has advantages with high LET (Linear Energy Transfer) and is considered to have direct damage on DNA to kill cancer cell. This characteristic feature lead to low OER (Oxygen Enhancement Ratio) and less dependence on cell cycle in tumour control. If we see physical feature, the beam has less multiple scattering than proton beam, and has advantage to form sharp dose distribution. At HIMAC in NIRS, about 10000 patients have been treated since 1994, and many kinds of tumours have been treated with excellent treatment results. In Japan, the first dedicated treatment facility of carbon beam had been constructed at Gunma University with government budget support. Following Gunma University, next facility has been constructed [1] in Kyushu with public private partnership by the budget support of Saga prefecture. Other construction cost come from private donations, and also investments. This financial structure is the first case to build carbon ion therapy facility.

In Ion Beam Therapy Center of SAGA HIMAT foundation, patient treatment has started at the end of August 2013. Since then, treated patient number increased rapidly, and 651 patients have been treated by use of two irradiation rooms (room A and room B) in 2016 financial year. This performance of treated patient number is more than the expected in a project plan [2, 3]. Considering this situation, we have decided to start a construction of the third treatment room (room C). In the room A and the room B, passive irradiation systems are equipped, which are well established irradiation method, and rapid increment of patient number has been possible. Though there are many treatment experiences by use of passive irradiation method with excellent results, we have decided to develop a scanning irradiation system in the room C. With this choice of irradiation method, we will have better flexibility in the cancer treatment. In the first stage, organ of no respiratory movement will be treated. In the second stage, we will treat respiratory moving organ.

SYNCHROTRON OPERATION

In our scanning system, beam range is controlled with the combination of the accelerator energy and the range shifter thickness. To obtain the required beam energy in the synchrotron, there are eleven operation energies from 100MeV/u up to 400MeV/u with fixed period of 5.2 seconds. To prevent drift of flat top magnetic field with synchrotron energy switch, maximum excitation pattern is added at the end of flat top. With this pattern, there is flat period of 3.2 seconds for beam extraction, and COD drift can be suppressed less than 0.5mm in the pulse to pulse energy change in the synchrotron operation.

TRANSPORT LINE

Beam line of SAGA-HIMAT is shown in Figure 1. In the design stage of the facility, we have planned to have the same optical condition at the iso-center in the three treatment rooms. In the room A and the room B, the passive irradiation systems were installed, and were used for treatment. When we have started the construction of the irradiation system in the third treatment room (room C), a scanning irradiation system was adopted. With this choice of scanning irradiation, beam spot size should be sharp, and this requirement makes change the position of triplet at the downstream in the beam line. To measure the beam size at the iso-center, we have used screen monitor. Obtained beam sizes are shown in Figure 2 for eleven energy steps in both cases of σ=1mm and 2mm ripple filter which are used to have broadening the Bragg curves. To obtain sharp dose distribution, the ripple filter of σ=1mm will be selected.

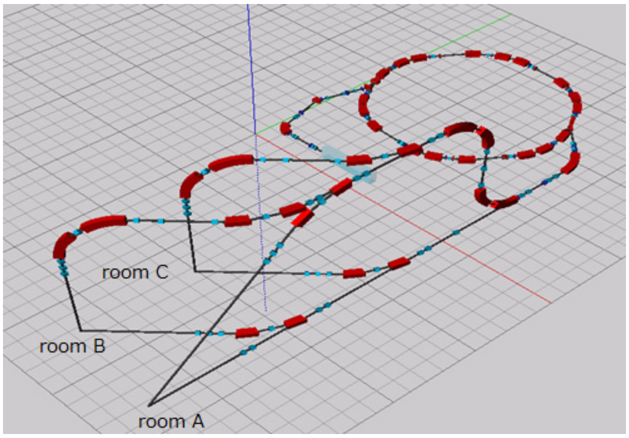

Figure 1: Beam line structure of SAGA-HIMAT.

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The obtained beam sizes (σ) of x and y directions are 1.17mm and 1.36mm with σ=1mm ripple filter at 400MeV/u, respectively. In the case of σ=2mm ripple filter, the sizes of x and y directions are 1.58mm and 1.70mm at 400MeV/u, respectively. In the case of σ=2mm ripple filter, we can obtain similar beam size in x and y directions where multiple scattering is dominant. This is not so in the case of σ=1mm ripple filter at higher beam energy, where beam size of x direction is more sharp than y direction with less multiple scatting effect.

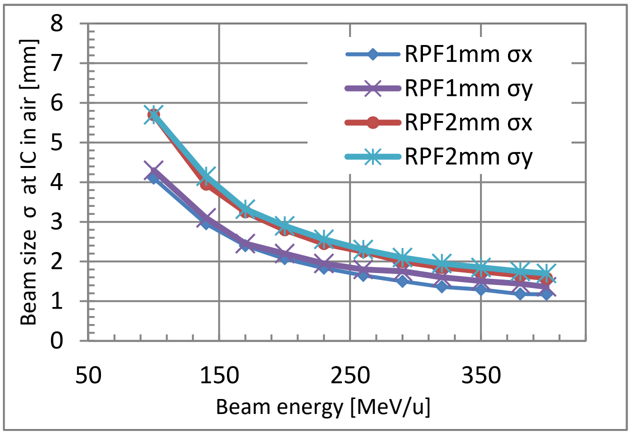

Figure 2: Beam spot sizes at the iso-center with ripple filter of σ=1mm and 2mm.

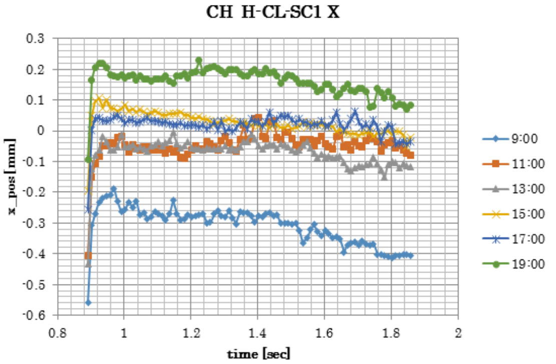

Figure 3: Drift of horizontal (x) beam position between 9 am and 7 pm measured with a screen monitor at the exit of the extraction channel from synchrotron. Data lines of each colours show beam position in one extraction period of synchrotron.

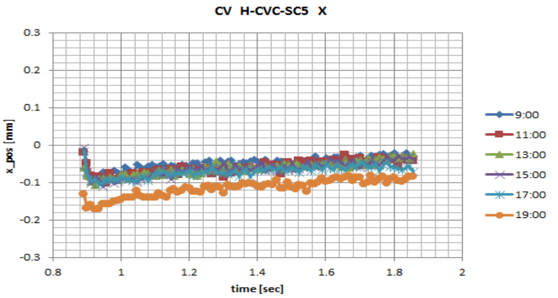

Figure 4: Drift of beam position of horizontal (x) direction between 9 am and 7 pm at the iso-center in the vertical beam line.

Concerning the beam position, we have checked its drift in a day from 9:00am to 17:00 with screen monitors in the horizontal and the vertical beam lines. In the test, we have chosen the beam energy of 400MeV/u, and started the synchrotron operation at 8:00 am. In Figure 3, measured data at the exit of the extraction channel are shown, where position drift of about 0.5mm was observed. Though there are beam position drifts, there was only small drift of about 0.1mm at the iso-center as shown in Figure 4. In these measurements, we have also observed vertical beam position drift of about 0.8 mm in the vertical beam line where vertical dispersion is 5.1 m. This means that there is the momentum drift in the extracted beam. This can be explained with change of lattice dipole field by use of following relation,

$$dB/B = \gamma_{tr}^2\, df/f + ((\gamma^2 - \gamma_{tr}^2)/\gamma^2)dP/P.$$

Here, we can assumed that df will be small with digital synthesizer, and extraction working point has γ_{tr}=1.712. We have drift of lattice dipole magnetic field as follows,

$$dB/B = ((\gamma^2 - \gamma_{tr}^2)/\gamma^2)dP/P$$
$$= -0.435\ dP/P.$$

In Figure 5, average beam position drifts in one synchrotron operation on the vertical beam line are shown. Beam track with momentum increment of 0.013% and lattice dipole field decrement (dB/B) of 5.7×10^{-5} is consistent with the measured data. This drift of magnetic field can be explained with temperature rise of the lattice magnet with 4.8 degrees, which is consistent with temperature rise of cooling water with 9.5 degrees at the exit. In the calculation, we have assumed no drift of beam direction at the extraction deflector. In the actual accelerator operation, lower beam energy operation will be also existed. In this case, field decrement of lattice dipole magnets will be small with lower temperature rise. From this reason, we can expect to have good beam position stability in the actual scanning irradiation.

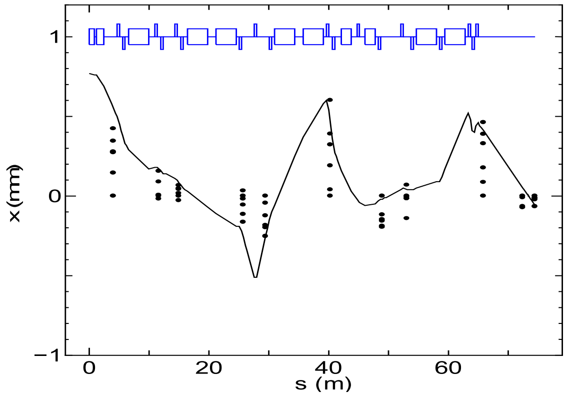

Figure 5: Drift of horizontal beam position in the vertical beam line, and an estimated track with momentum increment of 0.013% and $dB/B = -5.7\times10^{-5}$.

SCANNING SYSTEM

In our scanning system, beam range can be adjusted with combination of accelerated beam energy and thickness of range shifter. With this choice, we can make the irradiation system with relatively small number of accelerator operation files, and this helps us to have quick start up the scanning irradiation system. In the first stage, we will treat tumor with no respiratory gated irradiation, the gated irradiation will be applied in the next stage. To realize this with small modification of the system, high speed scanning system and high sensitive position monitor are equipped from beginning. In table 1, we show basic specs of the constructed irradiation system.

Table 1: Specs of the Irradiation System

Max. field size	220×220 mm^2
Beam energy	100 ~ 400 MeV/u, eleven steps
Range shifter	0.25 ~ 16 mm, seven leaves
Beam intensity	3 ~ 30×10^7 pps, five steps
Ripple filter	σ=1 mm (AL), σ=2 mm (PMMA)
Scanning speed	100 m/s (x), 50 m/s (y)

To check the accuracy of the scanned beam position, the scanned beam position monitor data are recorded where irradiated grid points are with 2mm spacing in x and y directions. As shown in Figure 6, the measured positions are scattered around planned points with accuracy of ±0.5mm. These deviations come from magnetic hysteresis of the scanning magnets. To improve beam position accuracy, we will use feedback with beam position monitor. For this purpose, there are two beam position monitors of main and sub. These monitors have sense wire of $20\mu m$ diameter with 1mm spacing. To have fast response, He gas with 20% CO$_2$ gas mixture is used. Using feedback, we have irradiated same grid points above. Obtained irradiated points are shown in Figure 7, where improved position accuracy is less than 0.15mm. This performance will be good enough for scanning irradiation.

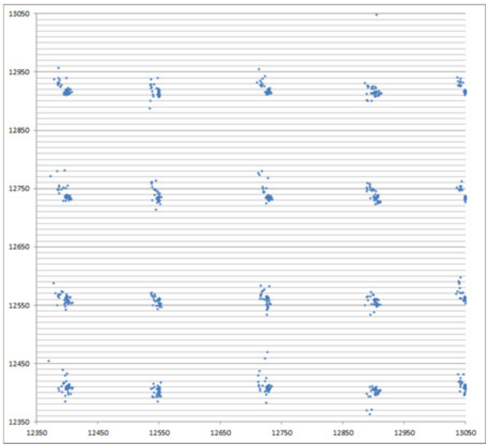

Figure 6: Irradiation for accuracy check of scanning magnet and power supply without beam position feedback.

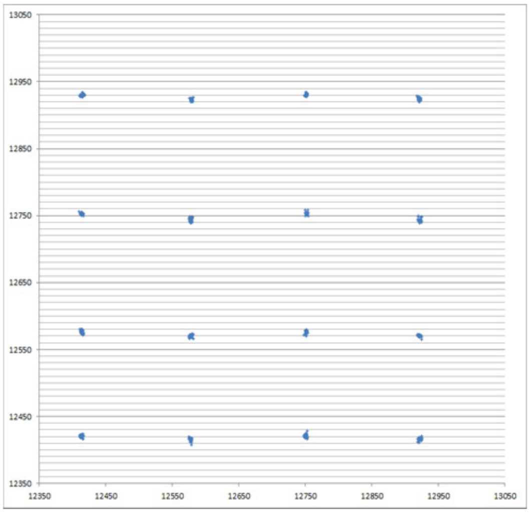

Figure 7: Irradiation for accuracy check of scanning magnet and power supply with beam position feedback.

TEST VOLUME IRRADIATION

To check the performance of the scanning system, we have irradiated the volume of 60×60×80mm^3 with ripple filter of 2mm (σ) and beam energies of 350, 380, and 400MeV/u. As shown in Figure 8, we have good agreement between calculated values and measured data of transverse dose distribution.

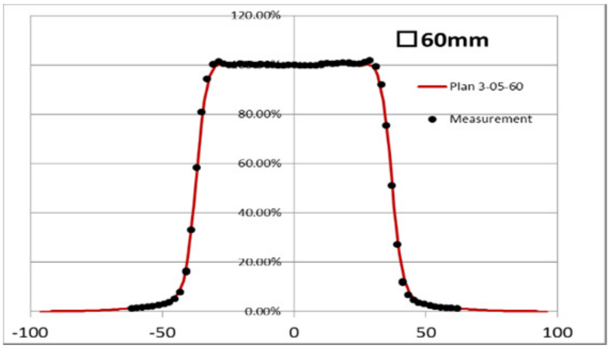

Figure 8: Measured transverse dose distribution at the center depth of SOBP. Red line shows the planned value.

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