IMPROVEMENT OF SCANNING IRRADIATION IN GUNMA UNIVERSITY HEAVY ION MEDICAL CENTER

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Abstract

Gunma University Heavy Ion Medical Center (GHMC) has constructed an experimental irradiation system of spot-scanning irradiation. Several improvements were carried out for the accelerator and the irradiation system.

For accelerators, slow extraction from a synchrotron using a transverse RF field is tested. Compared with conventional extraction system of RF acceleration, the deviation of the beam center position and the deviation of the beam size (1sigma) are reduced to the order of 0.1 mm and ripples of the beam spill (σ_I/I_{ave}) is reduced from 57% to 24%.

For irradiation system, 2-dimensional optimization of the irradiation planning was carried out for high-dose irradiation. After the optimization, the effective dose rate was increased from 1.8 Gy/min to 2.7 Gy/min with keeping the dose uniformity within ±2.5%.

INTRODUCTION

Gunma University Heavy Ion Medical Center (GHMC) is a compact heavy ion treatment facility [1] and have experienced a successful treatment operation for 5 years with 3 treatment rooms using broad beam (wobbling) irradiation system. In addition to these rooms, an experimental irradiation room for the research and development of a spot-scanning irradiation has been constructed. The purpose of this room is to research the feasibility of a treatment irradiation for smaller target and to establish the fundamental technique of the high-precision spot scanning irradiation. During the study with this system, several improvements were done in both accelerator and irradiation system.

The specification of the GHMC accelerator system is shown in Table 1. The accelerator is composed of an ECR ion source, a radio frequency quadrupole (RFQ) linac, an alternating phase focused interdigital H-mode (APF-IH) drifttube linac, and a strong-focusing synchrotron for a C^{6+} ion with a maximum energy of 400 MeV/u. The typical extracted beam current is 1.3×10^9 particle per second (pps) for whole acceleration/deceleration pattern, which corresponds to 4×10^9 pps in the extraction period.

In this facility, 3rd order slow extraction with RF acceleration is adopted. In the extraction period, the acceleration RF frequency is increased by 0.4% gradually and the area of the separatrix shrinks to realize the slow extraction. This method enables a quick start/stop of the extraction and gives a good reproducibility, but cause an energy variation during the extraction period. Since the range and position errors are critical in the scanning irradiation, this problem must be corrected [2].

This scanning post is also being used for biological experiment for the research of biological effect of locally high dose rate irradiation. The condition of irradiation is a beam current of 3×10^8 pps and an energy of 290 MeV/u and a spread out Bragg peak (SOBP) of 60 mm using binary range shifters. With the progress of the experiment, a request of high-dose irradiation of ~70 Gy came from the users. Since the original irradiation procedure [4], the effective dose rate was 1.8Gy, high-dose irradiation needs more than 30 minutes, which is longer than the duration of anesthesia for mice. Therefore it is necessary to improve the irradiation speed.

Table 1: Specification of the Treatment Accelerator

Ion Source (ECR w/ Permanent Magnet)	
RF Frequency	10 GHz, 180 - 240 W
Gas species	Methane (CH_4), 0.02 sccm
Beam Current	180 - 220 μA, 10keV/u C^{4+}
Linac (RFQ + APF IH-DTL)	
RF Frequency	200 MHz
RF Power (Tetrode)	140 kW(RFQ) 400 kW(IH-DTL)
Max. Field	23.6 MV/m (1.6 Kilp. Lim.)
Beam Energy	600 keV/u (RFQ) 4 MeV/u (IH-DTL)
Beam Current	170-210 μA, 4 MeV/u C^{6+}
Synchrotron	
Beam Energy	140 – 400 MeV/u
Circumference	63.3 m
Max. Bend. Field	1.5 T (Bρ=6.3 Tm)
Betatron Tune	(1.68, 1.23)
Chromaticity	-1.6 (Hor.)
Extraction Method	Slow Extraction (3rd order resonance of + RF Acceleration)
Max Beam Current	4×10^9 pps (Extraction Period)

EXPERIMENTAL SETUP

The overall view of scanning irradiation system is shown in Fig. 1. Four quadrupole magnets are placed at the end of the high energy beam transport (HEBT). A pair of scanning magnets scan the beam to move the beam

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spot by ±150mm at the isocenter. In order to realize a fast scanning speed, vacuum ducts in the scanning magnet are made of ceramic so as to reduce the eddy current. An extension beam duct is able to be inserted to minimize the beam size by reducing the scattering in the air. A dose monitor (ionization chamber) and a beam profile monitor (multi-wire proportional chamber) are used for the dose control and beam position/size monitoring, respectively. A mini ridge filter is inserted to spread out the Bragg peak slightly.

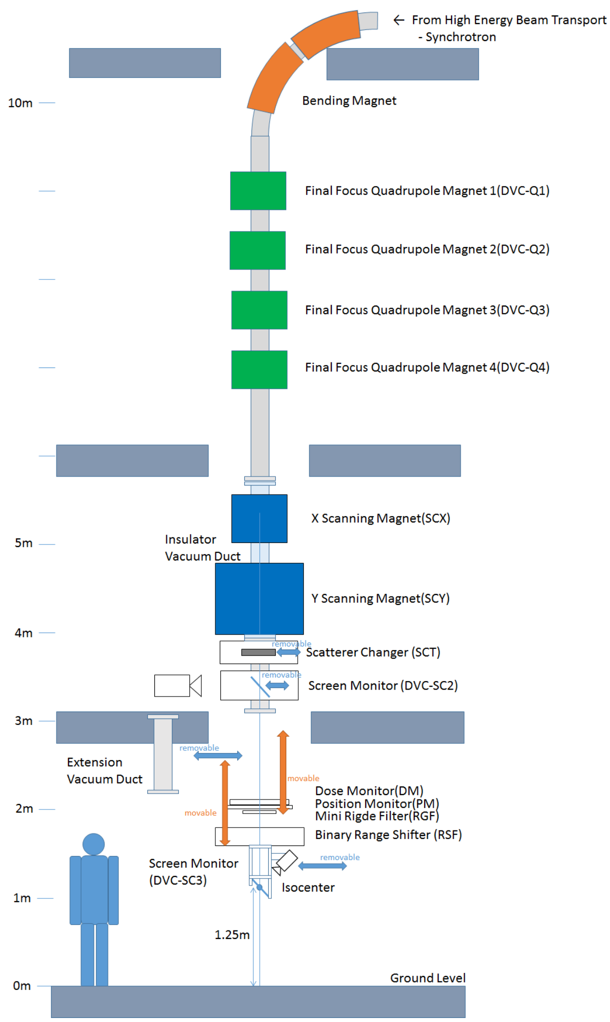

Figure 1: Layout of scanning irradiation port at GHMC.

IMPROVEMENT OF EXTRACTION FROM THE SYNCHROTRON

In order to improve the energy variation caused by the RF acceleration, beam extraction experiment using a transverse RF electric field was carried out [3]. Experimental setup of RF signal generation and parameters are shown in Fig. 2 and table 2, respectively. Two frequency modulated (FM) sinusoidal RF signals with FM phase difference of 180° was combined and amplitude modulated (AM) by a variable attenuator.

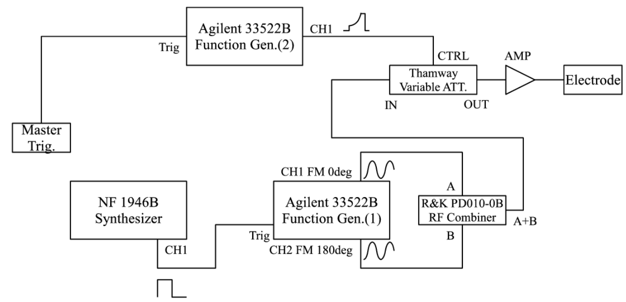

Figure 2: Experimental setup of RF signal generation.

Table 2: Setup of Transverse RF Extraction

Beam Energy	400MeV/u
Beam Current	3×10^{8} pps (Extraction Period)
Function Generator setup	Sine 200mVp-p FM 2.25-2.29MHz by 1kHz
Amplitude Modulation	Vgap: 90 – 390 V Kick angle: 0.15-0.62 μrad

With this extraction setting, beam positions were measured by a fluorescentt screen monitor at the isocenter of the scanning port. The position variation was kept within ±0.1 mm during the extraction as shown in Fig. 3. This result is better than the best result achieved by the acceleration extraction and a pattern-excited steering magnets [5].

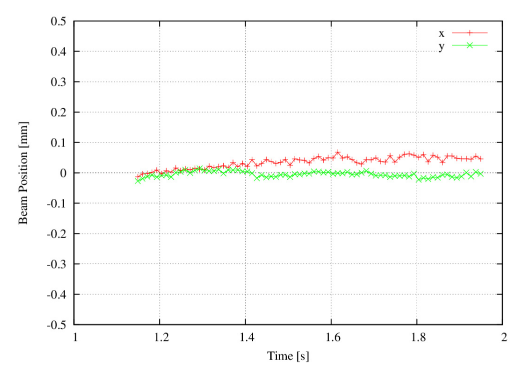

Figure 3: Beam center position during the extraction.

Extracted spill signal of acceleration extraction and transverse RF extraction were measured by the output dose monitor as shown in Fig. 4 and Fig. 5, respectively. The result of the acceleration extraction gives large spill ripples. The ratio of the standard deviation of the extracted beam current, σ_I and the mean extracted current, I_{ave} (σ_I/I_{ave}) was 0.57. The maximum current, I_{max} is 3.6 times larger than the mean current. Nevertheless, transverse RF extraction gives small spill ripples; the ratio of σ_I/I_{ave} and I_{max}/I_{ave} was 0.24 and 2.2, respectively. These reduction of spill ripples prevents a saturation of dose monitor and contributes to a stable profile measurement by a beam position monitor.

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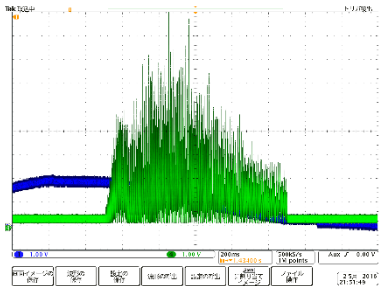

Figure 4: Beam spill by acceleration extraction.

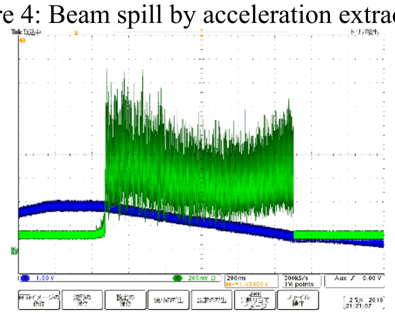

Figure 5: Beam spill by transverse RF extraction.

IMPROVEMENT OF DOSE RATE BY SPOT DOSE OPTIMIZATION

At the start of biological experiment in 2014, the dose rate with a SOBP of 60 mm was 1.5Gy/min with a uniform irradiation field of 102×102 mm. Since October 2014, 102×72 mm field (1.8 Gy/min) had been used for mice experiment with 102×28mm target collimator. In 2015, based on the request of higher dose rate from biological users, further optimization of the irradiation was carried out.

The procedure was a 2-dimensional irradiation plan optimization. The irradiation plan of scanning irradiation is to find a set of particle numbers for each spot. The preset value for the spot is represented by pulse numbers of the I/F converter output of dose monitor. The preset value for each spot was optimized based on the golden section search algorithm in order to realize a uniform dose calculated by a superposition of pencil beams. Fig. 6 shows the calculation result of uniform dose distribution.

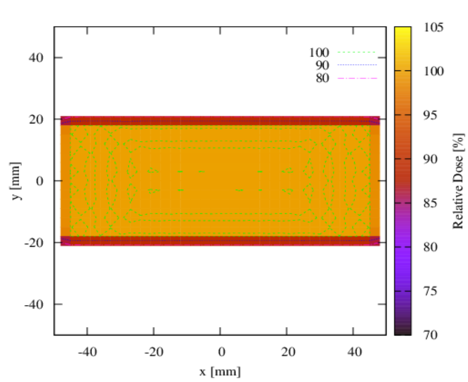

Figure 6: Calculation result of uniform dose distribution for 102×42mm irradiation field.

With this optimized irradiation, a uniformity of the irradiation was measured by gafchromic film (Ashland EBT-3). Fig. 7 shows the result of irradiation of 3.6 Gy (at the center of SOBP). This result shows an enough uniformity of ±2.5% for both x and y direction (Gantry coordinate). The dose rate was improved to 2.7 Gy/min. With this setup, a mice irradiation with 75 Gy was successfully carried out.

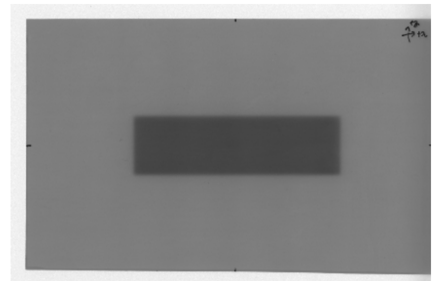

Figure 7: Scanned image of a gafchromic film irradiated with a 100×28 mm collimator. Dose uniformity in the irradiation field is kept within ±2.5%.

CONCLUSION

Experiments towards the treatment irradiation in the GHMC scanning port were carried out. For the accelerator, extraction using transverse RF electric field gave a beam axis stabilization within 0.1mm and a ripple reduction from 57% to 24%. Another improvement was done for the high-dose biological experiment. The dose rate was improved from 1.8Gy to 2.7 Gy.

Further improvement will be carried out for more precise and stable experiment. A dose feedback and a position feedback experiment will be tested soon.

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