BEAM COMMISSIONING OF THE NEW PROTON THERAPY SYSTEM FOR UNIVERSITY OF TSUKUBA

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Abstract

Beam commissioning of the new proton therapy system for University of Tsukuba was started in September 2000. The present system employs a synchrotron with a maximum energy of 250MeV and two rotating gantries. The beam was successfully accelerated up to 250MeV and transported to the irradiation nozzles. The position of the beam extracted from the synchrotron was confirmed to be very stable and sufficient flatness for the irradiation area was realized by using the dual ring double scattering method developed at University of Tsukuba. Furthermore, synchrotron operation triggered by patient respiration signal was succeeded.

1 INTRODUCTION

Construction and installation of equipment for the new proton therapy facility in the Proton Medical Research Center(PMRC)[1] at University of Tsukuba was completed in March 2000. Figure 1 shows a cut-away view of the facility, which consists of a 7MeV H^+ injector linac[2], a compact synchrotron with a 23m circumference[3], a high energy beam transport line, two treatment rooms, each with an iso-centric rotating gantry, and an experimental room with two horizontal fixed beam ports.

After tuning the equipment, beam commissioning was started in September 2000. The beam was successfully accelerated to 250MeV within a few days because the injector and injection transport line had been conditioned before installation in the new facility. In October 2000, a 250MeV beam was extracted from the synchrotron and transported to irradiation nozzles in the rotating gantries. The Bragg curves of the 250MeV beam were measured around the iso-center using a water phantom. In November 2000, the electric charge per pulse of the extracted beam was found to be about 6nC which corresponds to an average current of 2nA. The value was about one-third of the current sufficient for a dose rate of 2Gy/min in the maximum irradiation volume (20cmϕ×12cmSOBP).

In January and February 2001, dosimetry measurements of various irradiation volumes formed by using the dual ring double scattering method[4] were carried out for some energy levels. It was confirmed that the flatness of the irradiation area was sufficient. Since March 2001, beam test to increase beam intensity has been carried out. In April 2001, the extracted beam was increased up to 16nC per pulse.

To date, some requirements of accelerator system for medical use have been satisfied; the confirmed items are discussed in this letter.

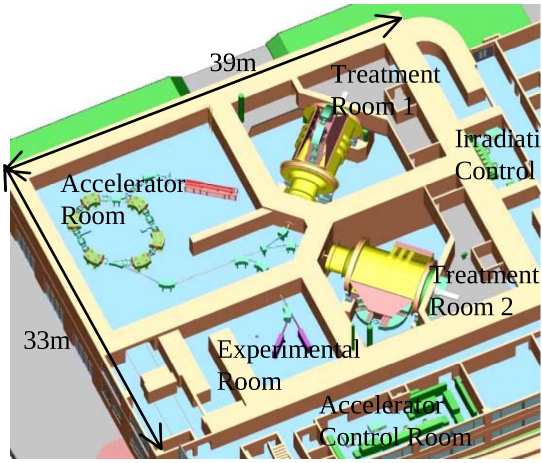

Figure 1: Schematic cut-away view of proton therapy facility.

2 SYSTEM CONFIGURATION

2.1 Accelerator

Accelerator parameters are listed in Table 1. A H^+ beam accelerated by the 7MeV linac[2] is horizontally injected into the synchrotron by a multi-turn injection scheme using two bump magnets. The synchrotron lattice design was previously reported[3]. Some changes between the present and the designed values have been made. The betatron tune was changed from the designed value (1.72,1.74) to (1.70,1.45) in order to prevent beam loss by difference resonance during the injection and capturing process. The rf cavity is an untuned type loaded with FINEMET cores[5]. After injection, the proton beam is captured through an adiabatic rf capture process. In order to increase beam intensity, dual-harmonics component is superposed onto the accelerating rf voltage[6]. The

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maximum magnetic field strength of the dipole magnet reaches over 1.7T when the beam is accelerated to 250MeV. The air slot design is used to keep field uniformity for various excitation levels[7]. To decrease B-Q tracking error and current ripple, power supplies for the dipole and quadrupole magnets include IGBT modules. Measured current ripple of the power supply for the dipole magnet is less than 2×10^{-6}(peak to peak). The accelerated beam is extracted by the horizontal third order resonance with constant separatrix[8].

Table 1: Accelerator Parameters

Particles	Proton
Injector	7MeV RFQ/DTL Linac
Injection Process	Multi-turn Horizontal Injection
Output Energy	70-250MeV
Number of Super periods	2
Circumference	23m
Dipole Magnet	60-degree Magnet with Radius of 1.4m
Maximum Magnetic Rigidity	2.57Tm
RF Frequency	1.6-8.0MHz
Betatron Tune ν_x / ν_y	1.70 / 1.45 at Injection 1.683 / 1.450 at Extraction
Extraction Process	Transverse RF Driven Slow Extraction
Repetition Rate	0.33-0.5Hz (for Normal Operation)

2.2 High Energy Beam Transport Line and Rotating Gantries

The proton beam extracted from the synchrotron is transported to the iso-center of each rotating gantries through the 35m long beam line. The beam line has 6 bending magnets, 18 quadrupole magnets and 6 pairs of vertical and horizontal correction magnets. These magnets are used to tune the beam parameters and position at both the entrance of the gantries and the irradiation points. The iron core of the bending magnets is made of stamped laminated steel in order to obtain reproducibility of magnetic field and to shorten the switching time of the energies and courses.

Each gantry can be rotated ±190 degrees. Although each rotating gantry weights about 200ton, the measured mechanical iso-center precision is found to be inside a cube of 1mm sides for all rotating angles.

3 PRESENT STATUS

3.1 Beam Intensity

The peak current of the injection beam from 7MeV linac is 6-8mA with pulse length 20µs. After multi-turn injection, the accumulated beam current measured by the current transformer is about 60mA, which corresponds to 2.3×10^{11} protons per pulse. After rf capture, the number of protons is measured by using a bunch monitor. Figure 2 shows typical measurements for the number of protons accelerated up to 250MeV. At the end of acceleration, there are 1.3×10^{11} protons. Horizontal and vertical tunes are measured and corrected by modifying the ramping pattern of the defocusing quadruple magnets during acceleration. Total efficiency from injection to the end of acceleration is about 55%.

For beam extraction, the horizontal tune is changed to 1.683 by controlling quadrupole magnets after the acceleration. After formation of the separatrix by exciting sextupole magnets, the beam is extracted by the horizontal perturbation using rf noise. The extraction can be switched quickly by this perturbation. Measured time for beam termination is less than a few hundred µs.

Extraction efficiency is more than 75% and 1.0×10^{11} protons are measured by Faraday Cup at high energy beam transport line.

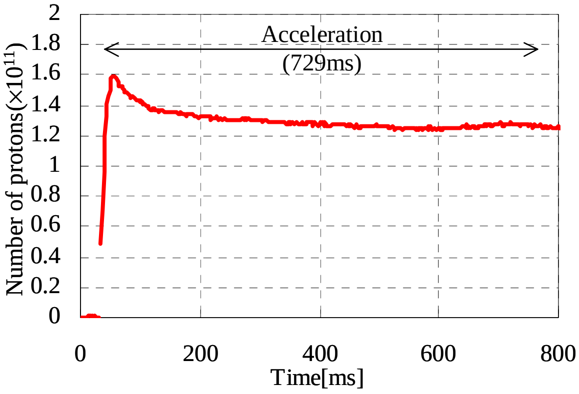

Figure 2: Number of protons accelerated up to 250MeV.

3.2 Measurement of Beam Energy

Protons have been accelerated to energies from 70 to 250MeV for 10 levels. The acceleration and extraction pattern of another energy level can be created within a few days. The beam energies are measured by a multi-layer Faraday cup (MLC) at the end of the straight section of the high energy transport line. Figure 3 shows the MLC energy measurement results. MLC consists of 480 copper

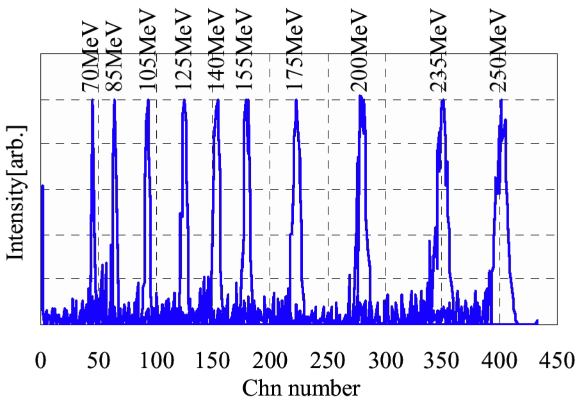

Figure 3: Results of energy measurement by MLC

electrode layers with each thickness equivalent to that of a 0.94mm deep water layer.

3.3 Stability and the Reproducibility of Beam Position

The position of the proton beam can be measured precisely by a high-resolution beam profile monitor located at the entrance of the irradiation nozzles. This profile monitor has wire grids with 0.35mm pitch and 1ms time resolution. Figure 4 shows the measured stability of the beam position for 10 hours. During the measurements, all of the operating parameters were kept constant. Figure 5 shows measured reproducibility of the beam position. After each measurement, power supplies of synchrotron and high energy transport magnet were shut off and restarted. These results indicate that the variation of beam position is less than ±0.2mm, which is sufficient for formation of a flat irradiation area by using the dual ring double scattering method.

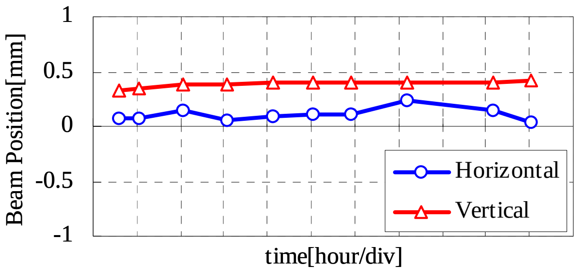

Figure 4 Stability of beam position

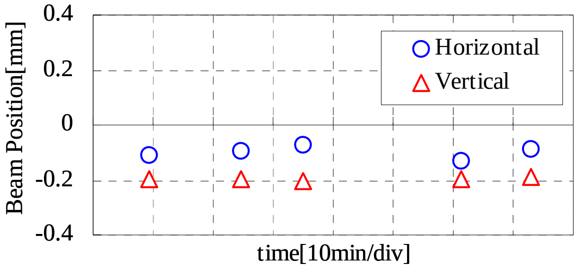

Figure 5 Reproducibility of beam position.

3.4 Respiration Synchronized Operation

Figure 6 shows the synchrotron operation can be triggered by a patient respiration signal. Two triggers, injection and extraction, were generated from a simulated signal of patient respiration. When the synchrotron received the injection signal, beam injection and acceleration were started sequentially. After the end of acceleration, the synchrotron was waiting for the extraction trigger. When it was received, the extraction sequence started and the beam was extracted. After the end of deceleration, synchrotron was waiting for the next injection trigger. In this operation, repetition rate of the synchrotron could be changed between 0.15 and 0.5Hz. Furthermore, the extracted beam could be terminated very quickly by stopping the rf perturbation when the extraction trigger ended.

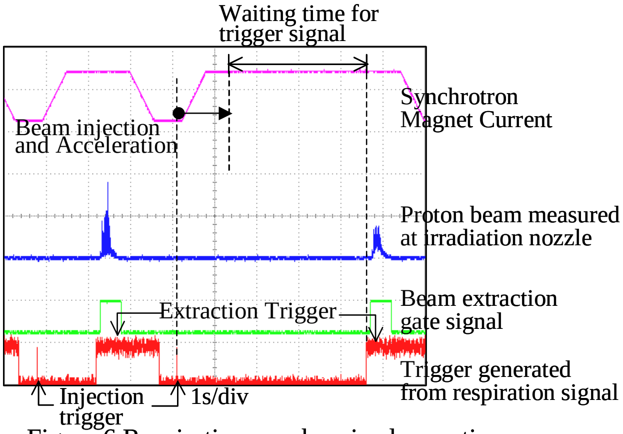

Figure 6 Respiration synchronized operation.

4 CONCLUSION

Beam commissioning of the new proton therapy system of Proton Medical Research Center, University of Tsukuba, has successfully proceeded. To date, the basic requirements of the accelerator system for medical use have been confirmed; 1.0×10^{11} protons per pulse were extracted from the synchrotron and transported to the irradiation nozzles. Ten levels of beam energy were extracted from the synchrotron and measured by multi-layer Faraday cup. The results of beam position measurements at the irradiation nozzles showed the sufficient stability and reproducibility for getting flat irradiation area by using the dual ring double scattering method. It was confirmed that synchrotron operation could be triggered by respiration.

In order to start patient treatment, dosimetry measurements for various irradiation areas and some biological experiment has been undertaken. Additional beam tests to increase beam intensity will be carried out next.

5 REFERENCES

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