OPERATION OF MEDICAL ACCELERATOR PATRO AT HYOGO ION BEAM MEDICAL CENTER

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Abstract

PATRO (Particle Accelerator for Therapy, Radiology and Oncology) is a medical accelerator facility for hadrontherapy of cancer at Hyogo Ion Beam Medical Center (HIBMC). Beam particles are proton (230 MeV) and carbon (320 MeV/u). After the beam commissioning and the tuning of irradiation system in 2000, we performed the clinical trials with proton and carbon beams from May 2001 until July 2002. We operated the accelerator for about 11,000 hours since the beginning of the beam tuning until the end of the clinical trials and for about 5,000 hours during the clinical trials. No serious troubles happened during the clinical trials. The stability and the reproducibility of the beams were well proved.

1 INTRODUCTION

Hyogo prefecture government had started a construction of the medical accelerator facility PATRO (Particle Accelerator for Therapy, Radiology and Oncology) for hadrontherapy with proton and carbon beams since 1995 in Harima Science Garden City, which is about 75km northwest of Kobe city. Figure 1 shows a bird's eye view of Hyogo Ion Beam Medical Center (HIBMC). An accelerator building for PATRO and a hospital with an inpatient ward (50 beds) are shown. After the beam commissioning and the tuning of irradiation system in 2000, clinical trials (with 30+30 patients) were performed in 2001 with proton and in 2002 with carbon. The Ministry of Health, Labour and Welfare approved a medical use of the facility with proton in October 2002. Proton radiotherapy will start in April 2003. Carbon radiotherapy will start after the approval of medical use with carbon beam, perhaps in 2004.

2 SPECIFICATIONS OF THE FACILITY

Beam particles of the accelerator facility include proton, helium and carbon. Beam energy ranges are 70 - 230 MeV/u (40 – 300 mm range in human tissue) for proton and helium, and 70 - 320 MeV/u (17 – 200 mm range) for carbon. The beam intensities are required to satisfy the dose rate of 5 GyE/min. for treatment volumes of 15 cm field size in diameter and of fully extended spread out Bragg peak (SOBP) over the maximum beam range. The facility consists of injector, synchrotron wit 93.6 m circumference, high-energy beam transport lines and patient irradiation system. Figure 2 shows a layout of the PATRO. The injector has two 10 GHz ECR ion sources with 35 keV/u output energy, 1 MeV/u RFQ linac, 5 MeV/u Alvarez linac and debuncher. The linac system accelerates H_2^+, helium (Q/A=1/2) and carbon (Q/A=1/3) up to 5 MeV/u. A stripper located downstream of Alvarez linac makes proton and fully stripped carbon ion. Operation rf frequency of the linacs is 200 MHz. Debuncher then reduces a momentum spread of the beam. Synchrotron ring is of a separated function type with a strong FODO focusing structure and its super periodicity is 6. Maximum rigidity of the ring is 5.58 Tm (B=1.38T). rf accelerating frequency range is 0.993 – 6.417 MHz with harmonic number 3. The maximum rf voltage is 5.2 kV. The beam is extracted by the third-order resonance scheme at tune 11/3.

The accelerator control system [1] consists of:
1) VME (Versa Module Europa) computers and Pattern Memories for synchrotron pattern and timing control.
2) PLC (Programmable Logic Controller) for control of DC power supplies, vacuum and monitors.

Figure 1: A view of Hyogo Ion Beam Medical Center.

Figure 2: Layout of the medical accelerator PATRO.

3) RIO (Remote Input Output) local controllers with optical fiber link distributed in DC power supply units.
4) Irradiation system I/F (interface) PLC.
5) PC (Personal Computer) with Windows NT for Man Machine Interface (MMI).
6) Ethernet and PLC networks.

These configurations satisfy a response time of data update cycle in MMI, change of power-supply current and pattern data loading. Interfacing with irradiation system establishes a QA (Quality Assurance) of the treatment. Figure 3 shows the accelerator control room. Area of the control room is 130 m^2. There are 2 sets (left and right) of console with 3 display screens, of which the central one is for MMI with mouse and keyboard, and another console (center) with 1 display as an operation file server.

We have 5 treatment rooms: A with Oblique (45-deg) port, B with Horizontal and Vertical ports, C with Horizontal port with patient sitting position (A-C for carbon and proton) and G1, G2 with isocentric proton gantry ports. A wobbler beam delivery system is used to produce transverse dose field uniformity. Ridge filter is used to obtain a spread out Bragg peak (SOBP). Table 1 summarizes the clinical requirement and physical specifications of the charged particle beams. Proton and carbon beams are used for the treatment. Further detail of the accelerator is described elsewhere [2,3].

3 BEAM COMMISSIONING

Installation of the apparatus started in March 1999. Beam acceleration test of injector linacs started in December 1999. In February 2000, full intensity beams of the linacs were obtained [4,5]. Synchrotron beam test started from end of March. We first started the beam test with He. 1-turn injection, multi-turn injection, rf capture, acceleration and slow extraction at 230 MeV/u were successively performed. Extraction efficiency larger than 80% was obtained. Beam intensity was enough to treat patient with dose rate of 2Gy/min. This was a maximum intensity officially permitted by radiation safety at that moment. Meanwhile extracted beams were successfully transported to the entrance of each treatment room. These results were obtained in about one month from the start of synchrotron beam test, including a period of about 1 week for control software debugging, etc. The operation parameter file (OPF) of synchrotron thus obtained by He beam tuning was used without modification to inject, accelerate and extract carbon beam at 230 MeV/u. The beam could be observed at beam transport line, although the intensity was about 3 orders of magnitude less than that of He beam.

Figure 3: Accelerator control room of PATRO.

Then we started a beam test with proton beam (230 MeV). In one day, beam was extracted with 10% of the required intensity. Soon the full intensity beam was extracted with extraction efficiency about 90%.

Finally we started a beam test with carbon (320MeV/u) in May after the increase of power demand of HIBMC up to 2.8 MW. This amount of power demand is maintained during the clinical trials and the proton radiotherapy that starts in April 2003. In the beginning of June, all beams (p, He and C) were extracted successfully with required intensity (although a limit of 2 GyE/min dose rate was still maintained) and with extraction efficiency 80 - 94%. Meanwhile the beams were introduced into the treatment rooms. Apparatus of irradiation system, including monitors for Dosimetry, were tested using beams. Further details of the synchrotron and its beam commissioning is described elsewhere [2].

After the completion of official examination on radiation safety in September, intensive test on irradiation system to form a uniform irradiation fields started. From December, a real simulation test of treatment with the participation of medical staffs started. Software of both treatment control system and accelerator control system was checked and revised.

In April 2001, an operation with full intensity beam, which enables the treatment with dose rate of 5 GyE/min, was permitted by official radiation safety office.

Table 1: Clinical requirements and physical specifications of the charged particle beams.

Particles	Proton, Helium and Carbon
Energy Range	70 - 230 MeV/u for p, He
	70 - 320 MeV/u for Carbon
Beam Intensity	7.3×10^{10} pps for p
	1.8×10^{10} pps for He
	1.2×10^{9} pps for Carbon
Dose Rate	5 GyE/min
Beam Range	40 - 300 mm for p and He
	13 - 200 mm for Carbon
Field homogeneity	±2% (over treatment field)
Field size	15cmx15cm for ports A, B
	10cmϕ for port C
	15cmϕ for gantry ports G1, 2
Displacement of beam	± 2mm (from isocenter)
Spill length	400ms
Maximum repetition	0.5 Hz for He and Carbon
	1 Hz for proton

4 DAILY OPERATION FOR THE CLINICAL TRIALS

During May – November 2001, clinical trials [6] with proton beam were performed. Every weekday at 5 o'clock in the morning, two operators come to the control room. They start a cooling water system and then patrol the equipments in accelerator room. In 20 to 30 minutes, temperature of the cooling water for linac cavities become stabilized. Then they set the power supplies of accelerator on. In 15 minutes, all power supplies become working. Then they start beam tuning by checking beam profiles and intensity at ECR ion source, linacs, synchrotron and high-energy beam transport line (HEBT) successively. In about 5 minutes, they check beam profile and intensity in front of a neutron shutter at the entrance of one treatment room. Then they introduce a beam into the treatment room and check the beam profile at isocenter, where tumor of patient will be located. They check beam profiles and their central positions in all treatment rooms and for several rotation angles of the gantries for three proton energies every day, i.e., 15-18 beam courses depending on the treatment request of the day (Different rotation angle of gantry is counted as one course.) for 150, 190 and 230 MeV of proton beam. These three energies cover the different beam range in human tissue required by the treatment. To change the beam course and check the beam profile it takes about 3 - 5 minutes. It takes about 15 minutes to change the beam energy and then check the beam profile in front of one treatment room. All parameter change of the (steering) magnet power supplies after the beam tuning and the resulting beam profile just in front of the neutron shutter are stocked in the memory of accelerator control computer for each beam course. These parameters are set on the request of beam course by medical staff for the treatment and the stocked profile is compared with a beam profile measured at that moment. At 8 o’clock, other operation staffs join the operation.

In the stage of clinical trial, we check the beam profile in all treatment rooms to take statistical data on the reproducibility of the beam position at isocenter. For the fixed beam, it is ±0.5-1mm. For the gantry, it is ±1mm.

From 9 o'clock, we start patient treatments. Intensity of proton beam supplied for the treatment is typically 7-8x10^{10} ppp with synchrotron pulse length T of 1.6 sec. Maximum number of patients treated in a day was 15 and the treatment was finished at about 5 o'clock in the evening. Patient Dosimetry is repeated every day for each patient. It is also measured even in the treatment room with no entry of the patient at that day to take statistical data on stability and reproducibility.

With statistical evidence obtained in the clinical trials on the stability, the amount of daily beam tuning in the morning and Dosimetry checking procedure will be reduced in routine operation for therapy.

During January – July 2002, clinical trials with carbon beam were performed. Operators started a beam tuning at 7:00 am, as the number of the patients were limited to five, no gantry port is applicable to carbon beam and the energies used for the treatment were 250 and 320 MeV/u. Carbon beam supplied for the treatment is typically 3.8x10^{9} ppp with synchrotron pulse length T of 3.3 sec.

5 START OF PROTON RADIOTHERAPY AND OPERATION OF THE MACHINE

After the approval of PATRO as a medical facility by national government on October 2002, the facility PATRO was delivered from manufacturing company, Mitsubishi Electric Corporation, to Hyogo Ion Beam Medical Center (HIBMC). HIBMC started the machine operation with its own responsibility. One shift operation is performed from 8:45 – 17:45 on weekday with 6 operation staffs from Accelerator Engineering Corp (AEC). 3 staffs works for accelerator operation and another 3 staffs works for QA of treatment irradiation system. Final tuning of accelerator and treatment irradiation system is performed. Software debugging is also performed. Ridge filters to form SOBP (Spread-Out Bragg Peak) are fabricated and tested by beams.

From April 2003, the proton radiotherapy and 2-shift operation during 6:00 – 22:00 will start. With another one staff for managing and operation, 13 operators of AEC work for the operation of PATRO. Saturday is for weekly maintenance. On Sunday and holidays, the machine is stopped. If some machine trouble happens on weekday, the machine will be operated on Saturday to recover the treatment.

Maintenances are scheduled two times in a year, one for 3 weeks and another for 1 week. As an interruption of treatment for more than four successive days means a failure of the treatment, the maintenance is strictly preventive.

6 CONCLUDING REMARKS

During two years clinical trials, with operation time of about 5000 hours, there were no serious troubles that interrupted the treatment. The stability and the reproducibility of the beams were well proved. Many debugging of the control programs were performed to reply demands and claims from medical staffs. The reliability of the facility was much increased.

7 REFERENCES

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