Hitachi Proton Beam Therapy System with Various Types of Rotating Gantries

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Hitachi, Ltd., Hitachi Research Laboratory

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Contents
- Overview of HITACHI
- HITACHI Proton Beam Therapy and Spot Scanning Technologies
- Recent Progress in Hokkaido Project
- Various Type of Rotating Gantries with Patient Positioning and IGRT configurations
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3 Outline of HITACHI

- Founded: 1910
- Consolidated Revenue*: 9,040 Billion Yen ($90.4 Billion, 1USD=100 JPY)
- Employees*: 326,240(*FY 2012)
- Main business activities in:
  - Power and Industrial Systems
  - Electronic Devices
  - Information and telecommunication systems
  - Digital Media & Consumer Products
  - High Functional Materials and Components
HITACHI provides healthcare solution to the medical society through diagnosis, therapy and information system and continue to expand as a part of focus to the infrastructure business.

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6  HITACHI Particle Therapy Supply Records

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>St. Jude Children Research Hospital, Memphis TN, U.S.A.</td>
<td>Two half rotating gantry rooms and one fixed beam room. All rooms equipped with scanning system. The e-arm type CBCT. The installation started in the October 2013.</td>
</tr>
<tr>
<td>2011</td>
<td>Mayo Clinic Rochester, MN / Phoenix, AZ, U.S.A.</td>
<td>Four half rotating gantry rooms and one fixed beam room. All rooms equipped with scanning system. The installation in Rochester started in the end of May 2013.</td>
</tr>
<tr>
<td>2010</td>
<td>Hokkaido University, Japan</td>
<td>One gantry room with scanning system. Real-Time Tumor tracking System, Robotic Couch and Gantry Mounted CBCT. Beam commissioning have been completed in the November 2013 as scheduled.</td>
</tr>
<tr>
<td>2008</td>
<td>Nara City Quality Life 21 Jouhoku, Japan</td>
<td>Two gantry rooms with one passive and one scanning system and one Fixed room. Treatment with passive started on Feb. 25th 2013. Treatment with scanning just started on Jan. 7th 2014.</td>
</tr>
<tr>
<td>2006</td>
<td>Heidelberg Ion Therapy Center, Germany</td>
<td>HITACHI supplied the RF acceleration system.</td>
</tr>
<tr>
<td>2002</td>
<td>MD Anderson Cancer Center / PROTON THERAPY CENTER, Houston, TX, U.S.A.</td>
<td>Three gantry room with two passive and one scanning system. Fixed room and Experimental room. PTC-H has treated total ~5,000 patients and ~1,100 patients with spot scanning till June 2013.</td>
</tr>
<tr>
<td>1998</td>
<td>Tsukuba University Proton Medical Research Center (PMRC), Japan</td>
<td>Two gantry rooms with passive system. PMRC treats many cases of Lung, Liver with respiratory gating. PMRC has treated 2,873 patients till January 2014.</td>
</tr>
<tr>
<td>1996</td>
<td>Wakasa-bay Energy Research Center (W-MAST), Japan</td>
<td>Multi-purpose system. Acceleration of proton, Helium and Carbon and is used for physics, biology and medicine. Medical research was shutdown on November 2009.</td>
</tr>
<tr>
<td>1995</td>
<td>National Cancer Center, Japan</td>
<td>HITACHI designed and constructed Gantry Room 1 and Fixed Room.</td>
</tr>
<tr>
<td>1994</td>
<td>National Institute for Radiology Science (HIMAC), Japan</td>
<td>HITACHI supplied the synchrotron, power supplies and control system.</td>
</tr>
</tbody>
</table>

7  Overview of HITACHI Proton beam therapy system

- **HITACHI PBT System**
  - Synchrotron accelerator with Injector LINAC
  - High Energy Beam Transport lines
  - Rotating Gantry and patient couch

**Key Features**

**Synchrotron**
- with RF-driven Extraction Technology
- Energy : 70 - 250MeV(for Passive)
  : 70 - 220MeV(for Scanning)

**HEBT**
- Course switching time < 45sec.

**Rotating Gantry**
- with High precision < ±1mm

**Irradiation Technique Capability**
- Passive(Wobbler+RF, DS+RF, DS+RMW)+MLC
- Spot Scanning(Discrete)
  - RF: Ridge Filter, DS: Double Scattering, RMW: Range Modulation Wheel
8 Spot Scanning Irradiation Nozzle

- HITACHI provides spot scanning dedicated nozzle.
- Smaller spot size is achieved by He/Vacuum chamber.

- Conformal Irradiation
  - Minimized Dose to Healthy Tissues
- Almost 100% of Beam Efficiency
  - Low Neutron Generation
- No Collimator / Compensator Necessary
  - Reduced Radioactive Waste
  - Shortened Radioactive Waste
- Less Mechanical Parts
  - Less spare parts

9 Discrete Spot Scanning Irradiation Scheme

- Beam turn on till spot dose attain to prescription dose.
- Beam switch off during scan from spot to spot.
- Energy change layer by layer with switching synchrotron operation pattern without degrader.
10 Beam Position Accuracy

- Synchrotron and HEBT parameters can be changed every cycle.
- Beam position is accurate and stable after Energy Change.

Deviation of spot position for a lateral 2D scanning (30cm x 30cm, 10,000 spots)

Deviation of beam center for consecutive energy scanning operation for 47 energy levels and 4 directions

11 HITACHI Scanning Irradiation Technology

- The first company that received FDA clearance for Pencil Beam Scanning in U.S. and started Spot Scanning Treatment in Commercial Based Hospital in the world.
- The first system in the world started Spot Scanning Treatment and started IMPT irradiation in the commercial based hospital.
- MDA has been treating patients for 5 years and completed about 1100 patients treatments with Spot Scanning.
100-110 patients are treated per day in 4 treatment rooms.
G3 Room (Scanning) is the busiest with 35 patients/day.
HITACHI realizes more than 97% availability for six year avg., (From 12/2011 to now: 99%)
NPTC has started treatment on 25th Feb. 2013 in Fixed Beam Room (FX).
NPTC has started treatment in Passive Gantry Room (G2) on 17th Jun. 2013.
217 patients have been treated as of 15th Jan. 2014.
Treatment system availability between Feb. 25th to Dec. 30th is more than 98%.
NPTC has started treatment in Scanning Gantry Room (G1) on 7th Jan. 2014.
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17 Motion Management with Tracking

- To realize precise treatment in moving organs by developing a Gated Spot Scanning Proton Therapy with Real-Time Tumor-Tracking system

**Real-time Tumor-tracking Radiotherapy** Developed by Hokkaido University

**Spot scanning Proton Beam Therapy** Developed by Hitachi, Ltd.
18 Compact Proton Synchrotron

- From Hokkaido System, HITACHI re-designed synchrotron to reduce cost and size with keeping required beam spec. for spot scanning
- The design has been verified based on our experience

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>New Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference</td>
<td>23m</td>
<td>18m</td>
</tr>
<tr>
<td>Footprint</td>
<td>42.5m²</td>
<td>27m²</td>
</tr>
<tr>
<td># of Magnets</td>
<td>(6,10)</td>
<td>(4,4)</td>
</tr>
<tr>
<td>Ion Source Type</td>
<td>With Filament</td>
<td>Without Filament</td>
</tr>
</tbody>
</table>

Cost and Size Reduction

Easy Maintenance

Ion Source Type With Filament Without Filament

Cost

Size

Reduction

Microwave Injector
LINAC

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# of Magnets

(Dipoles, Quads)

(6,10) (4,4)

3D Magnetic Field Calculation

Design Verification

Nozzle and Rotating Gantry

19 Irradiation Nozzle and Rotating Gantry

- Irradiation nozzle length: optimized design for spot scanning
  - Passive Nozzle 3.5m -> Scanning Nozzle 2.5m
- Rotating Gantry: minimum radius with 360 degree rotation

<table>
<thead>
<tr>
<th>Nozzle Length</th>
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<th>New Design</th>
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<tbody>
<tr>
<td>3.5m</td>
<td>2.5m</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>220ton</td>
<td>125ton</td>
</tr>
<tr>
<td>(Tsukuba, MDA, and Nagoya)</td>
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Modern Hadron Therapy Gantry Developments, Jan.17 2014

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20 Facility Layout and Radiation Shielding

- Space and Cost optimization-based beam transport design
- Less beam loss at synchrotron and beam transport
  Changing beam energy only by synchrotron itself -> Less Shielding

21 Recent Progress in Hokkaido Project.

- Beam commissioning has been started on-schedule and the basic performance of newly designed synchrotron system have been confirmed in the short period.
- Hitachi part of the commissioning was completed and the system was turned over to medical physics team in Nov. 2013.

Proton acceleration to 220MeV in the Synchrotron on the 5th day

220MeV Proton extracted on the 7th day

220MeV Proton transported to the iso-center on the 15th day
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23 Treatment Room and IGRT Device Layout

- Hitachi provides various type of Treatment Room Layout to meet the customer’s requirement.
  - Full Rotating Gantry with CBCT Capability
  - Half Rotating Gantry with Orthogonal FPD and X-ray
  - Half Rotating Gantry with C-arm CBCT/ in room CT
- Beam Characteristics for the multiple treatment room are identical based on our beam optics design.

Full Rotating Gantry With CBCT Capability(*)
Half Rotating Gantry With Fixed FPD and X-ray

*:developed with Hokkaido University
24 Compact Full Rotating Gantry Treatment Room

- Compact building layout while 360 degrees irradiation direction.
- Combined with robotic couch, high degree of freedom for patient positioning achieved.
- Gantry Mount Type CBCT is available.

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<thead>
<tr>
<th>No</th>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type</td>
<td>Full Rotating</td>
</tr>
<tr>
<td>2</td>
<td>Rotating Angle</td>
<td>From 0° to 360°</td>
</tr>
<tr>
<td>3</td>
<td>Isocentricity</td>
<td>Within 1 mm radius sphere</td>
</tr>
<tr>
<td>4</td>
<td>Max. Rotating Speed</td>
<td>More than 6 deg/sec</td>
</tr>
<tr>
<td>5</td>
<td>Couch Yaw Angle</td>
<td>+/-45 deg</td>
</tr>
<tr>
<td>6</td>
<td>2D Imaging</td>
<td>Orthogonal X-ray Imaging</td>
</tr>
<tr>
<td>7</td>
<td>CBCT</td>
<td>Gantry Mount Type</td>
</tr>
</tbody>
</table>

25 Compact Half Gantry Treatment Room

- Free open space around couch to allow easy access to patients.
- Compact building layout while achieving spacious treatment area.
- Combined with robotic couch, high degree of freedom for patient positioning achieved.
- The wide area will enable to mount the latest diagnosis systems such as CT on rails or PET/CT on rails.

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<td>Type</td>
<td>Half Rotating</td>
</tr>
<tr>
<td>2</td>
<td>Rotating Angle</td>
<td>From -5deg to 185deg</td>
</tr>
<tr>
<td>3</td>
<td>Isocentricity</td>
<td>Within 1 mm radius sphere</td>
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<td>4</td>
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<td>From 0 to 180deg</td>
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<td>2D Imaging</td>
<td>Orthogonal X-ray Imaging</td>
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HITACHI have continuous effort to provide a better solution of proton beam therapy by applying the most advanced technologies by collaboration with our customers.

We have developed various types of rotating gantry dedicated for spot scanning technique with various combinations with IGRT devices.