Particle Therapy using Proton and Ion Beams – From Basic Principles to Daily Operations and Future Concepts

Andreas Peters
(Heidelberg Ion Beam Therapy Centre, Germany)

Academic Training Lectures
CERN, 11th – 13th September 2012
Outline – Part 3

• Daily operations of a particle therapy centre: Experiences from the first five years at HIT in Heidelberg, from commissioning to the treatment of the first 1000 patients so far
• Future enhancements for synchrotron-driven particle therapy facilities: Magnetic field control and feedback, dynamic spill shaping and multi-energy operation within one synchrotron cycle
• Outlook to new accelerator concepts proposed for particle therapy: FFAGs, laser plasma accelerators, dielectric wall accelerators and others
From Commissioning by GSI to Operation by HIT

Commissioning Steps:

2006        Ion Sources and Linac
              *Hand-over to HIT: 06/2007*

2007/08     Synchrotron and HEBT Lines
              *Hand-over to HIT: 04/2008*

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Five Years of HIT Accelerator Operation

- Building up of the team from a core to the full operating crew
- Training of the team done by GSI, companies and “in-house”
- Internal organization of three technical teams
Five Years of HIT Accelerator Operation

- Building up of the team from a core to the full operating crew
- Training of the team done by GSI, companies and “in-house”
- Internal organization of three technical teams
- Establish regular shift operation from 16/5 to 24/7 for further commissioning steps including therapy control system evaluation
- Troubleshooting: e.g. a destroyed magnet connection box – repair within two days
Five Years of HIT Accelerator Operation

- Establish routine operation of the accelerator, especially consolidation of control system
- Achieved availability of about 98% in average – no longer break than 3 hours at daytime
- Daily Accelerator QA → retuning of linac, synchrotron and HEBT only every 3 – 4 months except intensity readjusting (daily – weekly)
- Patients treatment started on 15th November 2009 in one horizontal room, 1000 patients treated end of July 2012

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Five Years of HIT Accelerator Operation

- Restart of beam optical commissioning of the gantry after solving severe problems with the drag chain.

- 37,000 settings per ion in the CS, but only ~1-2% interpolation points are needed – adjustment sustained by an ion optical code (MIRKO by GSI).

- Accuracy achieved: Pencil beam within limits for scanning → possible treatment field 180 x 180 mm²; long-term stability under monitoring now.

Courtesy by A.v.Knobloch, Siemens
Five Years of HIT Accelerator Operation

- “2012 – Year of the Gantry”: Patient treatment start scheduled for mid/end of October
- Major change in shutdown strategy – during longer maintenance breaks of 2-3 weeks patients have to be phased out →”Ramping down” and “ramping up” necessary
- Since 2012 instead of two long shutdowns now six short maintenance periods of four days each (effectively 2.5 days) →Feasibility was successfully demonstrated!
# HIT Beam Time Schedule 2012
(July – December)

**Legend:**
- Patient treatment
- Maintenance
- Beam other than patients
- Shutdown

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Typical Day at HIT

24/7 rotation, 2 operators per shift

- plan verification
- gantry commissioning
- therapy protocols
- biophysics experiments
- quality assurance
- patient irradiation

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### HIT Operation - Statistics

(Numbers for 2012-2014 estimated)

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**2013: Major Upgrade of IONTRIS Treatment Software**
Enhancements of the HIT Accelerator facility
Magnetic Field Control in the Synchrotron

Goal: Reducing dead times in synchrotron cycle

Magnetic effects cause dead times: Dipoles → Eddy currents have to die out (a/1) before extraction process → Development of high sensitive measuring and feedback system

Graph: Dipole: Magnetic field error x1000

- Good field area
- Points labeled 1 and 2
- Time axis (t [s])
- Magnetic field intensity (B_\|)
Magnetic Field Control in the Synchrotron

Development of high sensitive measuring and feedback system: Normal feed forward system retrofit with pick-up coil, hall sensor and HIT integrator
Magnetic field control in the Synchrotron

Magnetic field compensation at work (b) → good field region reached within a few ms.

System in use since end of 2011:
Long-term stability (+/- 1mm) successfully demonstrated;
Time saving per synchrotron cycle: 700 ms
A similar system will be used for the four groups of quadrupoles to avoid “washing procedures” (see blue curve portion) needed because of hysteresis effects (including dipoles).

Possible time saving per synchrotron cycle: 950 ms (average)

[available: end of 2012]
Dynamic Intensity Control

- HIT uses 2-dimensional scanned beams for tumour treatment.
- Adjustable but predefined amplitude curve drive the transverse RF knock-out exciter producing more or less rectangular shaped spills.
- Treatment time per voxel is some ms. (Animation by courtesy of Siemens)
- A feedback loop has been implemented to avoid imperfections.
- Next step: A dynamic intensity adaptation during one spill with respect to the particular treatment plan is under development now.
- Shortening of treatment times of 20–40% possible! Implementation in 2013 foreseen.
Comparison: Cyclotrons vs. Synchrotrons

Persisting cw beam
Fixed A/Q
Passive energy variation

Discontinuous “dc beam”
Variable A/Q
Active energy variation

The pulsed beam of fixed energy is always present – it needs absorbers
A cycling beam of variable energy has 1-2 second gaps
Multiple Energy Operation within one Cycle

Developments at HIMAC/NIRS; fixed pattern of energies, stepwise deaccelerating of the beam → Goal: Minimize refilling of the synchrotron to save time

Current experiments under way to demonstrate the feasibility

→ Substantial extension of the control system necessary to achieve the needed flexibility!
Outlook to latest developments and new accelerator and s.c. gantry concepts
Latest Development: High-field s.c. Cyclotron

Main magnet material: Nb3Sn
B-Field: 8 – 10 T
Type: Synchrocyclotron
$E_{\text{max}} = 250$ MeV

Energy selection in the near of patient $\rightarrow$ neutron background?

Only scattering technique used

*With gantry structure $\rightarrow$ Single room solution possible!

Cost for such a facility: US $30$ Million
The MEVION S250 Proton Therapy System is USFDA 510(k) cleared and complies with MDD/CE requirements.

Installation at Washington University School of Medicine in St. Louis (2012)
New Accelerator Concepts - FFAGs

Idea:
Simplify control and operation, no synchronization necessary between B-field and RF

…but no savings in space!
New Accelerator Concepts - FFAGs

Fast acceleration

Compact footprint

Magnet aperture must accept large momentum range

Variable energy extraction?

Possible very high rep rate

Much world wide interest.

Demo machines in early operation, construction & design

Further projects: EMMA (GB), RACCAM (F) and others
New Concepts – Laser Plasma Accelerators

- Laser: 50 fs, 50 J (Petawatt!)
- \( I = 10^{21} \text{ W/cm}^2 \)
- \( 10^{11} \) protons up to 300 MeV should be possible (67 MeV reached end of 2009)

- Repetition rate?
- Intensity control?
New Concepts – Laser Plasma Acelerators

Serious proposal?

Mono-energetic beams possible in such a configuration?

Radiation background?
Oncoray Activities in Dresden

150 TW Ti:Saphir Laser Draco (Dresden laser acceleration source) – extension to 500 TW under way, Petawatt regime in planning

New building under construction

Later connection foreseen

Courtesy of Stephan Helmbrecht, Oncoray, Dresden
New Concepts – Dielectric Wall Accelerators

G. Caporaso et al, LLNL

250 MeV protons in 2.5 m?
Pulse-to-pulse energy & intensity variation
“Hoping to build a full-scale prototype soon”

Figure 1: Dielectric wall induction accelerator configuration.
Design of Superconducting Gantry

Carbon, 430 MeV/u (30 cm penetration depth)
Magnetic rigidity $B \rho = 6.6 \text{ T m}$
Present (normal) dipole: $B = 1.8 \text{ T}, \rho = 3.67 \text{ m}$
If superconducting dipole: $B = 3.3 \text{ T}, \rho = 2 \text{ m}$
Design of Superconducting Gantries

NIRS / HIMAC (J): 200 to, Radius: 5.5 m, L: 13m, 3 T

CEA (F) and IBA (B ): 210 to, Radius: 4m, Length: 13m, $B_{\text{max}}(90^\circ\text{-Dipole}): 5.39$ T (NbTi)

Use of cryocoolers foreseen

$\rightarrow$ Long recovery time in case of quenches!
NIRS Version of a s.c. Gantry

Use of combined-function superconducting-magnets for BM1～BM6 allowed to design a compact gantry.

Combined-function superconducting-magnets are also used for BM9 and BM10 to obtain square irradiation field and parallel beam.

Scanning magnets are installed here to obtain large scan size.

After NIRS
Two superconducting magnets are under construction, and will be completed by the end of March 2012.
HTS based Magnets for s.c. Gantries

Small prototype by Danfysik (InnovAcc)
Straight magnet with HTS wires (YBCO)
B = 3.6 T at 15 – 18 K
Homogeneity dB/B < 10^{-3} (r = 25 mm)

Use of cryocoolers, very smooth behaviour in case of quenches in contrast to LTS magnets
Acknowledgement


… and also the companies: Siemens PT, VARIAN Medical, IBA, Mitsubishi, Hitachi, Danfysik, SigmaPhi and some more not listed here.
Sources of Information

- http://ptcog.web.psi.ch/ (PTCOG home page)
- http://www.jacow.org/ (JACoW home page)
- https://indico.cern.ch/conferenceDisplay.py?confId=174714 (PARTNER workshop, CERN, March 2012)
- http://www.klinikum.uni-heidelberg.de/index.php?id=113005&L=1 (HIT home page)
Thank you for your attention!

(Intensity modulated raster scan, $^{12}\text{C}$ at 430 MeV/u), recorded on a film