The second generation scanning proton gantry at PSI

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PTCOG
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The framework – The PROSCAN project at PSI

- Dedicated superconducting cyclotron COMET
- Gantry 1 scanning patients since 1996
- Horizontal beam line for OPTIS 2 — no shut-downs since August 07
- Next generation scanning gantry: Gantry 2
  1. patients in 2009 – higher priority
  1. patient planned for end of 2010

Disconnected from ring cyclotron in 06
Innovation 1 - Easy access to the iso-center

- Gantry rotation limited to -30° to +180° (0° to 180° sufficient)
- Beam delivery flexibility by rotating the table in the horizontal plane
  - Analogy with longitude and latitude in the world-geography

- Expected advantages:
  - Fixed floor for a better access to the patient table
    - Nobody (patient or personnel) falling in the gantry pit
  - Fixed walls for mounting supervision equipment like Vision-RT
  - Large access space in front of the gantry for mounting commercial equipment
    - Like a sliding CT ...
**Innovation 2 - In-room positioning with sliding-CT**

- **Within reach of the patient table**
  - Installing a sliding CT of Siemens

- Same data as for treatment planning
  - No DRR

- Same table
  - No bending corrections

- Use of time-resolved images (4d) before (and after) treatment
  - Correct for intra-fraction motion
  - Adapt field to the organ situation of the day (soft tissues)
  - Setup and checks for respiration gating
Innovation 3 - BEV X-rays

- Retractable support with a flat panel
- X-ray tube on beam axis
  - Shining through a hole in the yoke of the 90° bending magnet
- For simultaneous use to proton beam delivery
  - Allows imaging with small air gap
    - Patient very close to the nozzle exit
  - Use of a single image in the beam direction
    - Instead of reconstructing from 2 tilted images
BEV: expected advantages ... and problems

- BEV imaging – an equivalent of portal imaging with photons
  - Very large field-of-view (26 cm x 16 cm)
    not masked by equipment or collimators in the beam path
  - QA control of gating
    pulsed X-rays synchronized with scanning
  - Beam guidance? (layers-tracking?)
    ...fluoroscopic mode?

- Neutron damage?

P100
S. Safai

Scan and bend

Bend and scan

a) compact gantry

b) long throw gantry

E. Pedroni    CPT - Paul Scherrer Institute  - PTCOG Heidelberg  05-10-2009
Innovation 4 – A compact optimized nozzle

- Vacuum “up to the patient”
  - Sharp pencil beam - 3 mm sigma
- Two monitors and a strip monitor
  - 2 mm strips (delivered by TERA collaboration)
- Removable pre-absorber
  - IN and OUT of beam (motorized)
  - For ranges below 4 – 10 cm
- Telescopic motion of the nozzle
  - To reduce air gap (keep patient at isocenter)
- Option to add collimator and compensators
  - To shield OAR on top of scanning
  - To simulate passive scattering with a scanning beam
- Collision protection to treat patients remotely (multiple fields in one go)
  - Field patching

Breaking of vacuum window tested
Sound measured below tolerance - if nozzle closed

E. Pedroni  CPT - Paul Scherrer Institute  - PTCOG Heidelberg  05-10-2009
**Nozzle: preliminary results - size of pencil beam**

- Use of minimal material in the nozzle for keeping the beam size between 3 and 4 mm sigma at all energies.

![Graph showing beam size (sigma) vs. energy](image)

- Measured while removing piece by piece the materials in the nozzle.
Innovation 5 - Fast changes of the beam energy

- **Continuous choice of the beam energy**
  - Setting all elements of the whole beam line within a single command (from steering file to MCR)

- **Constant beam transmission from COMET to gantry**
  - “Compensation” of degrader losses from 100 to 200 MeV

- **Fast energy changes**
  - Cyclotron (fixed energy)
  - Fast degrader ahead of the gantry
  - The beam line follows the energy variations in the degrader

- **Shown**
  - 80 ms dead time for small range steps of 5 mm
Example

- Time pattern of main scanning devices of a scan of a 65 mm dose box (2940 Spots)

Degrader

90° Bending magnet

Beam monitor

An order of magnitude faster than any other system
Needs to take into account hysteresis effects …

- Fixed magnetic ramping (100-230 MeV)
  - Red: up-down
  - Blue: down-up
- Measured with a water phantom

- Energy setting
  - Red: tunes with wrong ramp
  - Blue: right order of ramp
- Measured with a stack of ICs

P46 S. Lin
P136 C. Algranati
Innovation 6 - Double parallel scanning

- **Fast parallel lateral scanning**
  - T sweeper 2 cm/ms
  - U sweeper 0.5 cm/ms

- **Scan area of 12 by 20 cm**
  - Plus motion of patient table for treating larger field sizes
  - Experience with Gantry 1

- **Parallelism**
  - Table used as a sweeper-offset
  - Simplify
    - Treatment planning
    - Field patching
    - Errors from compensators
    - Dosimetry
Well focused beam for all energies…

- Parallelism
  - Max deviation ~4 mrad (edge of field)

Achieved by connecting a short correction quadrupole in series with the U sweeper.
Innovation 7 - Vertical deflector plate (COMET)

- **Dynamic use of the modulation of the beam intensity**
  - Deflector plate and vertical collimators in the first beam turn after the ion source
  - Time delay to extracted beam in the order of 100 us

- **Example**
  - Delivery of line segments with changing voltages on the deflector plate
  - "Pulsing beam"
Innovation 8 - A very flexible control system

- Steering file for combined delivery of
  - Spots
    - Spot scanning as the default (starting) mode
  - Lines
    - For maximum repainting number and simulated scattering
  - Contours?
    - For optimizing repainting and lateral fall-off (difference Gaussian to error-function)
- Passive scattering
Innovation 9 - Tabulated dose delivery with FPGA

• Combined tabulated control of
  – U-sweeper
  – T-sweeper
  – Beam intensity
    • As a function of time

Example 1 – U T meander path

Example 2 - Dose box with continuous scanning
494 energy layers (85 ms per layer)
(6 x 8 cm) in less than 1 minute
Innovation 10: Simulated scattering

- Magnetic scanning at max. speed
  - Constant intensity per energy layer
- Dose shaping with collimators and compensators (LEIGHT WEIGHT)
  - BEV shaped layers
- Very high repainting number
  - Most distal layer (200ms)
    - 88 scans / liter / minutes
- Improved uniform scanning
  - Simulate scattering on a scanning-gantry
  - With a parallel beam
  - With variable modulation of the range
    - Shrinking shape of layers proximally
  - Part 2 of thesis work of S Zenklusen
Innovation 11 – Fast volumetric repainting

• **For conformal scanning and IMPT** (without collimators and compensators)

• **Painting of lines**
  – With maximal possible velocity ~ 2 cm / ms, 0.5 cm/ms
  
    • *except for those regions where the dose rate are not high enough...*

  – Dose shaping with Beam Intensity Modulation (I.M.)
  – <10 ms per line (10cm + line change)

• **Painting of energy iso-layers**
  – < 200 ms per plane (20 lines x 5 mm)
  – Change of energy (100 ms - 5mm range)

• **Repainting of iso-layers**
  – ~ 6 s per liter (20 energies at 5mm steps)

• **Volumetric repainting capability (aiming at)**
  – 10 repaintings / liter in 1 or 2 minutes
Innovation 12 – Time driven dose control

- Time driven devices U - T - I
  - Dose control with a feedback loop
    - Input: required dose rate
    - Difference to Monitor 1
    - Output vertical deflector plate

- Paths with variable speed and/or variable intensity

Dose linearity of simple T-lines

10 cm in 20-200 ms

1 time * 0.5
Constant intensity
Variable T speed

5 ms is the limit ... systematic errors !!!

23 times
Max T speed
Variable intensity

10 cm in 5 ms

P64
D. Meer

Delivered MUs

10 ms

1000
500
0
2000
1500
1000
500
0

Required Dose

0
0.2
0.7
1
Conclusions

- **Encouraging results with**
  - Beam optics (successfully commissioned)
  - Small beam spot size
  - Double parallel scanning
  - Very fast dynamic beam energy changes
  - Very fast delivery of energy layers
  - Dose control via beam intensity

- **Still waiting for**
  - Control of patient table and gantry rotation
  - Patient handling equipment
  - Architectural finishing of the area

Scintillator block - the beam of Gantry 2 seen with a TV camera

Many thanks to the involved colleagues at PSI for their help and to YOU for the attention