A Specialized High-Power (50 kW) Proton Beamline for BNCT

Morgan P. Dehnel, Thomas M. Stewart, Tue Christensen, David E. Potkins, D-Pace, Inc., PO Box 201, Nelson, BC, Canada
Hirofumi Seki, Shinji Shibuya, Steve Domingo, Glenn James, Pat Creely, Steve Bucci, AccSys Technology, Inc., 1177 Quarry Lane, Pleasanton, CA 94566, USA

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Outline:

- Motivation for Accelerator Based BNCT
- Ion-Optics
- HEBT Beamline
  - Ion-Optical Elements (Magnetic)
  - Upstream Horizontal Section
    - Magnets, Vacuum, Diagnostics, Support
  - Downstream Vertical Section
    - Magnets, Vacuum, Diagnostics, Support
    - Generic Target Distribution
- Next Steps
Motivation for Accelerator Based BNCT 1:

- Boron Neutron Capture Therapy (BNCT) is a two step non-invasive therapeutic treatment of cancer.
  
  1. Tumour-localizing Boron-10 delivery agents are injected into the patient.
  2. The patient is exposed to epithermal neutrons which have a very high probability of reacting with the concentrated Boron-10 in the cancer cells resulting in an energetic $\alpha$ and a recoiling nucleus which ionize molecules within 5-9 microns killing the cancer cell.
Motivation for Accelerator Based BNCT 2:

- BNCT has a 50 year history at research nuclear reactors.
- Strong growth in BNCT implementation in hospitals is anticipated, since:
  - It can be de-coupled from nuclear reactors by use of particle accelerators.
  - Low energy \((p,n)\) reactions require inexpensive accelerators.
  - Accelerator-based systems can be turned-off (relatively safe).
  - Accelerator-based systems are compact.
  - PET techniques provide much better dosimetry.
Ion-Optics 1:

- 20 mA (ave), 2.5 MeV, protons, 50 kW, CW, 400 MHz.
  - Twiss parameters provided by AccSys for 1 rms (35.9% beam intensity) thru 10 rms (99.3% beam intensity)
  - Initial D-Pace design undertaken with 1st Order Beamline Simulator code.
  - In order to provide acceptance overhead for space-charge emittance growth ensure that 3x 10 rms emittance envelopes can be transported without loss.
  - AccSys physicists confirm beamline acceptance is appropriate with space-charge based beam transport modeled with TRACE-3D
Horizontal and Vertical 1-10 rms emittance beam envelopes through the HEBT Beamline for the case of a 10 mm diameter DC Target Spot Size. The quadrupole magnet settings are: \( HQ1 = 2,993 \, \text{G} \), \( VQ2 = 2,337 \, \text{G} \), \( VQ3 = 1,557 \, \text{G} \), \( HQ4 = 1,397 \, \text{G} \).
Ion-Optics 3:

3 x 10rms Emittance  Horizontal and Vertical beam envelopes. This plot confirms that a 30 rms beam envelope can be passed through the system. This provides reasonable acceptance overhead to ensure that 2.5 MeV proton beam losses will be < 1% (i.e. apertures confirmed). The quadrupole magnet settings are as follows: HQ1 = 3,033 G, VQ2 = 2,307 G, VQ3 = 1,827 G, HQ4 = 1,607 G.
10rms, 2x 10rms, 3x 10rms Emittances used to yield Horizontal and Vertical beam envelopes can pass through the bending magnet's 0° thru port to yield up to a 100 mm beam spot according to AccSys' needs. This provides reasonable overhead to ensure that beam losses will be < 1% for 2.5 MeV protons (i.e. apertures confirmed). The quadrupole magnet settings are as follows:

1x 10 rms Emittance Beam: HQ1 = 3,306 G, VQ2 = 2,105 G
2x 10 rms Emittance Beam: HQ1 = 3,116 G, VQ2 = 1,985 G
3x 10 rms Emittance Beam: HQ1 = 3,026 G, VQ2 = 1,934 G
HEBT Beamline 1: Ion-Optical Elements (Magnetic)

(1) Upstream Quadrupole Doublet:
- Bore = 82.3 mm
- Effective Length (EL) = 202.3 mm
- BMax = 0.4 T

(2) DC XY Steering Magnet:
- Iron Gap = 105 mm
- EL = 184 mm
- BMax = 0.01 T

(3) 90° Bender Magnet:
- Iron Gap = 52 mm
- Pole Face Rotations = 0°
- Bore = 82.3 mm
- EL = 300 mm
- Pole Shape = Rogowski
- BMax = 1.3 T

(4) Downstream Quadrupole Doublet:
- Bore = 82.3 mm
- EL = 202.3 mm

(5) AC XY Scan Magnet:
- Iron Gap = 97 mm
- Frequency = <100 Hz
- EL = 212 mm
- BMax = 0.4 T
- BMax = 0.0165 T

All magnets designed with alignment fiducials for Ball Mounted Reflectors (BMR) used with laser tracker.
HEBT Beamline 2:

- DC XY Steerer
- NPCT
- Downstream Quadrupole Doublet
- Thru Port Line
- Water-Cooled Sapphire Low Power Beam Profile Monitor
- AC XY Scan Magnets
- Cryo-Pump & Gauge Station
- Upstream Quadrupole Doublet
- 90° Bender Entrance/Exit Colimators with Readbacks
HEBT Beamline 4: 
Upstream Horizontal Section
HEBT Beamline 5:
Upstream Horizontal Section - Bender

Bender Vacuum Box

Bender Entrance/Exit Collimator

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HEBT Beamline 6:
Downstream Vertical Section

LiNAC: 20 mA, 2.5 MeV Protons
Upstream Quad Doublet, DC XY Steerer
90° Bender, Entrance/Exit Collimators
Thru Port Line
TARGET 1
Downstream Quad Doublet
Horizontal & Vertical AC Scan Magnets
Beam Current Monitors (GMW/Bergoz)
Cryo-Pumping
Sapphire Beam Profile Monitor with RadHard Camera
TARGET 2
HEBT Beamline 7: Downstream Vertical Section

Quadrupole Doublet  NPCT  XY AC Scan Magnets

Low Power Sapphire Beam Profile Monitor
HEBT Beamline 8:
Generic Target Distributions

**Generic Circular Beam Intensity Distribution**

*Figure 8: Beam density for radius varying from 5 mm to 45 mm. 10 rms beam spot diameter = 10 mm.*

**Generic Rectangular Raster-Scanned Beam Intensity Distribution**

*Figure 16: Beam density distribution for XY scan with 10 mm diameter 10 rms beam with 4.5 mm spacing in Y.*
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THE END

Thank You Very Much