The first year of operation of PSI’s new SC cyclotron and beam lines for proton therapy.

*Marco Schippers, Jürgen Duppich, Gudrun Goitein, Eugen Hug, Martin Jermann, Anton Mezger, Eros Pedroni,*

*for the PROSCAN team (>50 persons)*
PROSCAN: Stand-alone facility at PSI

January-June 2007

Diagram of the facility with labels:
- Cyclotron
- Degrader
- EXPERIMENT
- OPTIS-2
- Med. Pavillon
- Gantry-1
- Gantry-2
- 10 m scale
- PROSCAN: Stand-alone facility at PSI

Marco Schippers, Cyclotron conf., Catania Oct. 1-5, 2007
Acceptance tests of cyclotron
Commissioning of beam lines
Operation experience
Acceptance tests and commissioning of cyclotron
250 MeV SC-cyclotron

basic design: NSCL (Henry Blosser)
Delivered by ACCEL/Varian

an intensive collaboration

Sign contract: April 2001
Extracted beam: April 2005
Beam on Gantry-1: June 2006
First patient: Febr 2007
Levels of Quality Assurance of cyclotron

- Measurements for information & reference, *not specified*
e.g.: field maps

- Acceptance of subsystems *(factory acceptance by ACCEL)*
e.g.: coil-winding
  vacuum

- Acceptance tests *(37) defined by PSI*
  acceptance measurements
  e.g.: beam quality
  nr. of beam interruptions
  access to components / exchange time
  acceptance checks
  e.g.: documentation

Dec 05 - Febr 06
33 done & OK
Energy measurement

Ion chamber in water tank to measure proton range

Range in water => E=250.4(1) MeV
Reliability: beam interruptions

Result:
- No beam during 3.0 minutes (spec: <6 min=1%),
- nr longer than 10 sec = 2 (spec: <5)

unscheduled interrupts, automatic restart, 10 hour test
Beam on/off and stability

Necessary for fast dynamic scanning (Gantry-2)

Vertical deflector in cycl. Center

- beam on/off

Acceptance tests:
- repetition rate 1 kHz
- beam off < 50 μsec
- intensity stability σ<5%

(for Gantry-1 and München: √)

On/off by means of Vertical deflector

Beam intensity

0 0.5 1.0 1.5 2.0 time (ms)

40 μs

0.6 0.7 0.8 ms
Scan modes of new Gantry-2

Spot scanning: step & shoot

Cont. scanning “TV” mode

kHz-Intensity modulation

7 s for a 1 liter volume.
Target repainting: 17 scans / 2 min.
Fast intensity control with Vertical Deflector

Intensity + beam scanning:

15 cm / 30 ms

David Meer, Christian Hilbes, (Dec. 2006)
Intensity control

- Max intensity set by: Ion source + phase slits

Roles of deflector plate:
- decrease drift of intensity
- set requested intensity within 5%

Febr. 2007: start program to reach spec=> best: σ =3 % (see poster)
Extraction efficiency

Electrostatic extraction elements

R$_{ex}$ R=30 cm

Measurement of current on probe: Extr eff= 80.6%

R=30 cm: 100%

Routine: 80-83%
>80% extraction efficiency: Low dose to service staff

24 h after beam off, June 2007
(extracted beam integral 72 μA.h):

- on pole, closed cap: 400 μSv/h (40 mrem/h)
- mid plane, open pole cap: 250 μSv/h (25 mrem/h)

inside cyclotron

Mid plane, open cap
Commissioning of beam lines
Beam-energy adjustment

Degrader unit

Steerer  Q  Q  Q  Kicker

Carbon wedge degrader
238-70 MeV
5 mm ΔRange in 50 ms
Energy scanning, Estep ~5 mm range in water.
Energy: Degrader error sensitivity

Slit aperture: $\frac{dp}{p} \pm 0.5\%$

If degrader-error $\pm 5$ MeV:

- highest sensitivity at high energy
- if degrader error $< 1$ MeV:
  mainly transmission loss.

$E$-shift (MeV):

- 200 MeV: $\pm 1.5$
- 90 MeV: $\pm 0.2$

Range Variations:

- $\sigma = 0.4$ mm
- $\sigma = 0.4$ mm
- $\sigma = 0.3$ mm

$=> \sigma E < 0.05\%$

Cycl+beamline
Transmission

measured transmission with "OPTIS" collimators

Behind E-slits
\( \Delta p/p = +/-1\% \)
Dual scattering system for OPTIS-2

Transmission = 0.5% at 70 MeV, dp/p=+/- 1% => Optimize scattering system

Beam →

1st foil widens beam

2nd foil flattens beam

W
Al

Dual Ring: eff. = 36%
Multiple Ring: eff. = 57%

The Multiple Ring solution follows the ideas presented by Yoshihisa Takada (poster PTCOG43)

Test foil made by laser ablation (Fachhochschule Windisch)

Design model tested and confirmed at HMI
Operation experience
### Operation during patient treatment

**Febr-May 2007: 18 patients treated at Gantry-1**

#### PROSCAN Status

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMAC3</td>
<td>121 nA</td>
</tr>
<tr>
<td>SOL</td>
<td>120 nA</td>
</tr>
<tr>
<td>Vdef.</td>
<td>0.54 kV</td>
</tr>
<tr>
<td>Degr.</td>
<td>162 MeV</td>
</tr>
</tbody>
</table>

| Kicker       | 60.0 A       |
| HF           | 120.4 kW, 8.40 V |
| Extractor    | 50.0 kV, 50.0 kV |
| Hauptmagnet  | 158.49 A     |
| Phase        | 95 Grad      |
| Ionquelle    | 2.22 kV, 518.7 mA, 0.49 cc/min |

**Mastership: Gantry 1**

**Graph and Data:**

- BMA1: Device offen
- BMBI Gantry2: Device fachrt
- BMEI Gantry1: Device offen

**RPS/Safety switch box:**

- Ionenquelle
- HF reduziert
- HF
- Ablenkplatte
Operation statistics
first 15 weeks of patient treatment

HF power, extracted beam, arc current of ion source.

Machine “Up” when:
HF “on”
AND
Ion source “high”

961 hours Up Time
18 patients Gantry-1

Avail = 1 - \frac{Unsched\ Down\ Time}{Up\ Time}
Analysis of Unsched. Down Time

UDT per week: occurs as single events

⇒ MTBF (UDT>0.5 h) ≈ 1.5-2 weeks (typically at start up)
Conclusions and Outlook:

- We are happy with performances of cyclotron and beam lines
- Last problems are being solved
- Patient treatment has started at Gantry-1 and runs successfully

Currently in progress: (see poster)

⇒ acquire experience and optimize operation
⇒ commissioning OPTIS-2
⇒ installation Gantry-2