Status of Linac4

Ion Source Review, 14 November 2013

M. Vretenar, CERN
2013: a memorable year!

A cheering crowd celebrating the first beam accelerated by the RFQ, 13.3.2013

Klystrons and modulators installed in the Linac4 Hall

The RFQ installed in its final location in the tunnel, 25.6.13

Open Days 2013: 2’500 visitors!

7.11.2013: ready for 3 MeV beam tests in the tunnel!
1. Pre-injector (source, magnetic LEBT, 3 MeV RFQ, chopper line)
2. Three types of accelerating structures, all at 352 MHz (standardization of components).
3. Beam dump at linac end, switching magnet towards transfer line to PSB.

### Energy and Length Table

<table>
<thead>
<tr>
<th>Component</th>
<th>Energy [MeV]</th>
<th>Length [m]</th>
<th>RF Power [MW]</th>
<th>Focusing</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFQ</td>
<td>0.045 - 3</td>
<td>3</td>
<td>0.6</td>
<td>RF</td>
</tr>
<tr>
<td>DTL</td>
<td>3 - 50</td>
<td>19</td>
<td>5</td>
<td>112 PMQs</td>
</tr>
<tr>
<td>CCDTL</td>
<td>50 - 102</td>
<td>25</td>
<td>7</td>
<td>14 PMQ, 7 EMQs</td>
</tr>
<tr>
<td>PIMS</td>
<td>102 - 160</td>
<td>22</td>
<td>6</td>
<td>12 EMQs</td>
</tr>
</tbody>
</table>

### Other Parameters

- **Ion species**: H^−
- **Output Energy**: 160 MeV
- **Bunch Frequency**: 352.2 MHz
- **Max. Rep. Frequency**: 2 Hz
- **Max. Beam Pulse Length**: 0.4 ms
- **Max. Beam Duty Cycle**: 0.08%
- **Chopper Beam-on Factor**: 65%
- **Chopping scheme**: 222 transmitted / 133 empty buckets
- **Source current**: 80 mA
- **RFQ output current**: 70 mA
- **Linac pulse current**: 40 mA
- **Tr. emittance (source)**: 0.25 π mm mrad
- **Tr. emittance (linac exit)**: 0.4 π mm mrad

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The 3 MeV injector (ion source, LEBT, RFQ, chopper line) has been commissioned with beam in March-May 2013 on a test Stand.

- **19.2.2013**  First usable H- beam (45 keV)
- **13.3.2013**  Beam through RFQ
- **16.4.2013**  Beam through chopper line
- **21.5.2013**  Switch to protons (for higher intensity)
- **31.5.2013**  End of the beam tests, start transfer to tunnel

First 3 MeV beam on transformer: 10mA H-accelerated through the RFQ at first shot!

Hard time to get there, but commissioning completed in just 3 months!

Bunch Shape Monitor: phase profile of the bunch along the pulse

Emittance scan
Transverse emittance measured for different solenoid settings.

Beam reconstructed at source output and effective space charge estimate.

16-20 mA current
0.7-0.8 mm.mrad
The Linac4 RFQ

Completed in September 2012 (some delays in design, machining, brazing).
RF conditioning in less than a week, commissioning with beam started on 13.3.2013 and completed on 28.3.
Compact and solid design, aiming at high reliability.

The Linac4 RFQ not only focuses and accelerates the beam as required, but so far it does it in a stable, reliable and reproducible way!
- 70-75% RFQ transmission achieved at nominal settings (<94% design value, but as expected and confirmed by simulations because of the bigger input beam emittance)

- LEBT H2 gas pressure was changed to study experimentally the effect of neutralisation
Chopper line (MEBT), 3.6 m:
- 2 choppers (double meander lines on ceramic substrate) inside quads;
- 3 bunching cavities;
- 5 quadrupoles;
- Steerers and diagnostics.
- Chopper dump (conical)

Quadrupoles used to increase separation chopped/unchopped beam reducing the required chopper voltage (600 V).

Worked perfectly, rise time (to avoid beam loss) measured by the transfos <10 ns (waiting for more accurate time resolved measurement).
Longitudinal emittance reconstruction

Reconstruction

RFQ

BU.1 fixed

BU.2 varying

BU.3 OFF

Measurement

Reconstructed

Measurement

Simulation

Measurements

ΔE (keV)

21

22

Δφ (°)

7.8

8.8

NA-PAC’13 - Pasadena - 30 September 2013 - First commissioning experience with Linac4 - JB. Lallement
BSM / Feschenko monitor

First commissioning completed by INR team

BSM measurements
- Infrastructure (Electrical, cooling, ventilation, all cabling) completed
- Waveguides and circulators installed
- 12 klystrons /17 installed
- 6 modulators /14 installed
- Ion source, RFQ, MEBT line installed, HW tests completed
- All safety clearances passed on 8.11.13, beam tests starting…
## Commissioning schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
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<tbody>
<tr>
<td>Commissioning Linac4</td>
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<tr>
<td>H-source installation &amp; commissioning</td>
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<tr>
<td>RFQ and chopper line installation</td>
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<tr>
<td>3 MeV HW and beam tests</td>
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<tr>
<td>DTL1 installation</td>
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<tr>
<td>DTL1 commissioning</td>
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<tr>
<td>DTL2/3 installation</td>
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<td>DTI 2/3 commissioning</td>
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<td>H-source 2 installation &amp; commissioning</td>
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<td>HW commissioning 100 MeV</td>
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<tr>
<td>CCDTL installation</td>
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<tr>
<td>Transfer line installation 1</td>
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<tr>
<td>Linac4 ready for 50 MeV protons</td>
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<tr>
<td>CCDTL beam commissioning</td>
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<tr>
<td>Transfer line installation 2, alignment</td>
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<tr>
<td>PIMS installation</td>
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<tr>
<td>HW commissioning 160 MeV</td>
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<tr>
<td>PIMS commissioning</td>
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<tr>
<td>Beam tests, reliability run</td>
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<tr>
<td>160 MeV beam tests</td>
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<tr>
<td>Reliability run 2016</td>
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</table>

- **3 MeV test stand completed**
- **3 MeV from Oct. 2013**
- **12 MeV, 50 MeV from April 2014**
- **100 MeV from Dec. 2014**
- **160 MeV from mid 2015**
- **Reliability run 2016**
Next steps: DTL and CCDTL

- DTL Tank 1 assembled, under RF tests.
- DTL Tanks 2 and 3 in construction and assembly.
- All 7 CCDTL modules (50-100 MeV) delivered, stored and progressively under HP tests.
When are we going to connect Linac4 to the booster and with what particle?
- Linac4 will be completed at end 2016.
- Converting to H- the PS Booster injection takes 9.2 months (incl. 2 months cool-down and renewed cabling).
- LHC will restart in 2015 and run for 3-4 years: it is very difficult to obtain an intermediate stop for Linac4 connection (although physics has plans for a 4.5 months interruption at end 2016).
- Options:
  a. (favored): connect with H- at end 2016 (intermediate shut-down for physics) or at end 2017 (early Long Shut-down).
  b. (back-up): use Linac4 as 50 MeV proton injector replacing or in parallel with Linac2 between end 2016 (intermediate physics shutdown) and end 2018 (maximum for long Shutdown start), increasing (proton) current to 80 mA (half current and half emittance than Linac2).