MAX IV Commissioning

Mikael Eriksson on behalf of the MAX IV team

IPAC 16/Busan
Summary

• The MAX IV Facility
• The MAX IV 3 GeV Ring
• Commissioning Highlights
• Conclusions – Next Steps
MAX IV – an overview

Linear Accelerator

1.5 GeV SR

3 GeV Storage Ring

Short Pulse Facility

Annika Nyberg, MAX IV-laboratoriet, 2012
<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>3</td>
<td>GeV</td>
</tr>
<tr>
<td>Current</td>
<td>500</td>
<td>mA</td>
</tr>
<tr>
<td>Emittance</td>
<td>0.2 - 0.33</td>
<td>nm rad</td>
</tr>
<tr>
<td>Circumference</td>
<td>528</td>
<td>mA</td>
</tr>
<tr>
<td># straight sections</td>
<td>20 × 5 m</td>
<td></td>
</tr>
</tbody>
</table>
Civil Engineering

Shear Wave Velocities

Concrete, 0.3m, >2400 m/s

Stabilized UGM, 0.3m, 1300 m/s

Shale/Mudstone, 1100-1200 m/s

North-East Clay Till, 8-13m layer, 400-650 m/s

Lime Stabilized Soil, 4m in average, >900m/s

Low Baltic Clay Till, 2-8m layer, 250-300 m/s

Large Footprint, No Isolated Foundations for Roofs etc.

Poisson’s Ratio = 0.48

www.ekdahlgeo.se
Beam parameters Thermionic Gun

<table>
<thead>
<tr>
<th>MS1</th>
<th>MS2</th>
<th>MS3/TR3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td>270 MeV</td>
<td><strong>Energy</strong></td>
</tr>
<tr>
<td><strong>Energy spread</strong></td>
<td>0.5 % (fwhm)</td>
<td><strong>Energy spread</strong></td>
</tr>
<tr>
<td><strong>Norm emittance x</strong></td>
<td>12 mm mrad</td>
<td><strong>Norm emittance x</strong></td>
</tr>
<tr>
<td><strong>Norm emittance y</strong></td>
<td>4.7 mm mrad</td>
<td><strong>Charge</strong></td>
</tr>
<tr>
<td><strong>Charge</strong></td>
<td>~ 280 pC</td>
<td><strong>Charge</strong></td>
</tr>
</tbody>
</table>

Slide by S. Thorin

May 2016
The MAX IV 3 GeV ring Lattice

7-bend achromat
20 periods
The MAX IV 3 GeV ring Lattice

7-bend achromat
20 periods

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodicity</td>
<td>20</td>
</tr>
<tr>
<td>Circumference</td>
<td>528 m</td>
</tr>
<tr>
<td>Horizontal tune $\nu_x$</td>
<td>42.20</td>
</tr>
<tr>
<td>Vertical tune $\nu_y$</td>
<td>16.28</td>
</tr>
<tr>
<td>Natural horizontal chromaticity $\xi_x$</td>
<td>-49.984</td>
</tr>
<tr>
<td>Natural vertical chromaticity $\xi_y$</td>
<td>-50.198</td>
</tr>
<tr>
<td>Momentum compaction (linear) $\alpha_c$</td>
<td>$3.06 \times 10^{-4}$</td>
</tr>
<tr>
<td>Horizontal damping partition $J_x$</td>
<td>1.8471</td>
</tr>
<tr>
<td>Bare lattice emittance $\varepsilon_0$</td>
<td>0.328 nm rad</td>
</tr>
<tr>
<td>Bare lattice energy loss per turn</td>
<td>363.8 keV</td>
</tr>
<tr>
<td>Bare lattice natural energy spread $\sigma_\delta$</td>
<td>$0.769 \times 10^{-3}$</td>
</tr>
<tr>
<td>Bare lattice horizontal damping time $\tau_x$</td>
<td>15.725 ms</td>
</tr>
<tr>
<td>Bare lattice vertical damping time $\tau_y$</td>
<td>29.047 ms</td>
</tr>
<tr>
<td>Bare lattice longitudinal damping time $\tau_E$</td>
<td>25.194 ms</td>
</tr>
<tr>
<td>Horizontal beta function at center of LS $\beta_x^*$ (bare lattice)</td>
<td>9.00 m</td>
</tr>
<tr>
<td>Vertical beta function at center of LS $\beta_y^*$ (bare lattice)</td>
<td>2.00 m</td>
</tr>
</tbody>
</table>
MAX IV 3 GeV Ring DC Magnets

- Each cell is realized as one mechanical unit containing all magnet elements.
- Each unit consists of a bottom and a top yoke half, machined out of one solid iron block, 2.3-3.4 m long.

- a U5 bottom half →
- ↓ an assembled U5
MAX IV 3 GeV ring vacuum system layout

Slide by E. Al-dmour
MAX IV 3 GeV ring vacuum system layout

Slide by E.AI-dmour
MAX IV 3 GeV ring vacuum system layout

Slide by E.Al-dmour
MAX IV 3 GeV ring vacuum system layout

Slide by E. Al-dmour

- BPM
- Ion pump location
- Absorber location
- Sector valve location

Beam direction
3 GeV Ring Commissioning Timeline

- Beam in TR3
  - Aug 11 2015

- First Turn
  - Aug 25 2015

- Stored Beam
  - 0.1 mA
  - Sep 15 2015

- Stacking
  - 4 mA
  - Oct 08 2015

- First Light
  - Nov 2 2015

- 120 mA
  - Jan/31 2016
Threading the beam – first turn – many turns

2015/08/25
3 passes
All correctors OFF

2015/08/26
35 passes

2015/08/27
First Stored Beam

Injected beam

Stored beam 2 seconds after previous injection pulse

Injection

Kicker Current

2015/09/15
Capture and Bunching

First pass
500 MHz from Chopper

100 turns

150 turns

175 turns

200 turns

Plots S. Leeman

May 2016

IPAC 2016
Linear Optics Characterization: Integer Tunes

![Graph showing linear optics characterization with integer tunes](image-url)
LOCO: reduction in dispersion beating

Before LOCO

After LOCO
Chromaticities:

**Figure 1: Tune Shift vs. Momentum**

- For horizontal tune:
  
  \[-46.1147 \left( \frac{dv}{dp} \right)^2 + 1.0982 \frac{dv}{dp} + 0.20941\]

- For vertical tune:
  
  \[0.3647 \left( \frac{dv}{dp} \right)^2 + 1.958 \frac{dv}{dp} + 0.28901\]
BPM Offsets

- Measured by BBC using trim coils in sextupole magnets

RMS: 144 µm H / 138 µm V
Orbit Correction

Residual RMS: 0.7 µm H / 62 µm V
Injection Efficiency - 2

Graph with data points and annotations:
- Current
- Charge in TR3

10 mA/min @ 2 Hz
142 pC/shot
Average Efficiency = 142/188 = 76%
Vacuum Conditioning - pressure

Average Normalized Pressure [mbar/mA]

Dose [A.h]

P = P0 * D^(power)

power = -0.88 ± 0.004
P0 = 1.78e-010 ± 1.28e-012

All vacuum gauges in S2 except RF cavities
I = 50 to 55 mA
Beam Lifetime

![Graphs showing beam lifetime over time with current and AmpCav loops values.](image-url)
Aperture Scans – scraper measurements

Plot by Jens Sundberg

Vertical aperture scaled to center of LS 2.3 mm

2011 simulations by S. Leemann
Collective Effects – Single Bunch

- No signs of TMCI up to 8.55 mA (nominal 2.8 mA/bunch).
- Significant bunch lengthening even without harmonic cavities.

Data by J. Breunlin, A. Andersson, G. Skripka, R. Nagaoka
Collective Effects - Multibunch

- Possible to store >120 mA without feedback and without harmonic cavities. Predicted RW threshold was only ~ 40 mA!
- HOM driven longitudinal motion is evident at a few mA in uniform fill.
- Temperature tuning has proved effective in fighting longitudinal CBI.
- Harmonic Cavities not fully tuned-in yet. Need more conditioning.
- Preliminary BBB feedback tests using a short stripline showed a longitudinally stable beam up to 35 mA.
- Longer striplines for BBB feedback to be installed in February.
- Longitudinal Actuator (cavity) under design.
Sigma polarized SR, 632.8 nm, SRW calculation (left) and measured image (right). The simulation is done for $\varepsilon_x = 320$ pm rad, $\beta_y = 1.5$ m. Both figures show a 2 x 2 mm$^2$ area of the image plane. The fringe pattern is too weak to be visible.

Optical magnification of $m=-2.28$ is taken into account in the SRW model
Horizontal opening angle: 6 mrad
Vertical opening angle: 8 mrad
Exposure time: 2.9 ms
Horizontal intensity profile of imaged sigma polarized SR. Due to the reduced horizontal opening angle the fringe pattern is not as pronounced as it could be, but easier to understand and to calculate.

Present setup is limited by optical aberations (from misalignments) and surface quality from optical components (some are inherited from MAX II, MAX III). Steady improvements during the next weeks are planned. Camera linearity might also be an issue!

Challenges on the SRW model side are to include for example: variation of dipole field, variation of beta_x, variation of vertical opening angle, along the observed electron beam path.
Main Problems/Difficulties

- RF Cavity Conditioning
- RF System commissioning (LLRF, Shunt Groups)
- Diagnostic System Commissioning
  - BPMs
- Kicker Magnet PS failure
- Gun Klystron Failures
- Long Radiation Surveys
- Cooling System Failures
- Control System Commissioning
- PS Failures
Next Steps

- February 2016: First two in-vacuum undulators
- March to July 2016:
  - Further conditioning of RF cavities
    - Main cavities
    - Harmonic cavities
  - Further linear optics trimming
    - LOCO, shunting
  - Non-linear optics trimming
  - Collective Effects studies (Harmonic cavity tuning)
  - Bunch-by-Bunch feedback commissioning
- May 2016: 2 EPUs in the 3 GeV Ring, Transfer Line and Last Achromat in 1.5 GeV ring
- September-December 2016: 1.5 GeV ring commissioning
- November 2016: Friendly users (3 GeV ring)
- March 2017: First open call users (3 GeV ring)
- Feb 2017: First Ids in the 1.5 GeV ring
- May-June 2017: LINAC RF upgrade
Conclusions

● Progress with the initial phase of MAX IV 3 GeV ring commissioning gives us increased confidence that the MBA concept is sound.

● Much is still to be done to reach the final design specifications, but nothing indicates there is any fundamental obstacle ahead.

● Most difficulties are related to technical subsystems that need time for conditioning/maturing
Thank You!

Photo: H. Tarawneh

Photo: S. Thorin

Photo: L. Isaksson