First Optics and Beam Dynamics Studies on the MAX IV 3 GeV Storage Ring

S.C. Leemann†, M. Sjöström, Å. Andersson, MAX IV Laboratory, Lund University, SE-22100 Lund, SWEDEN

Introduction

• MAX IV 3 GeV storage ring is ***the first MBA-based light source to go into operation***; beam commissioning started Aug 2015.

• First stored beam on Sep 15, stacking achieved Oct 8, first light on Nov 2 (on first of two diagnostic beamlines).

• Since Nov 2015 running with top-up injection and closed SOFB loop.

• First two IDs (2-m long, 18-mm period IVUs) installed Feb 2016, gaps closed to 4.5 mm and first data taken by June 2016.

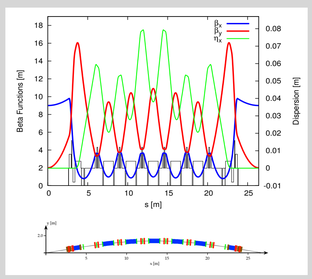
• Facility inaugurated on June 21, 2016, during summer 2016 installed one IVW and two EPUs.

• So far peak current of 198 mA stored, highly efficient injection/stacking performed with only a single dipole kicker.

• Routine delivery of 50 mA for BL commissioning and first experiments.

Table 1: MAX IV 3 GeV storage ring design parameters.

Stored current I	500 mA
Circumference C	528 m
Main RF f_{rf}	99.931 MHz
Bare lattice emittance ε_0	328 pm rad
Betatron tunes ν_x, ν_y	42.20, 16.28
Linear chromaticity (natural) ξ_x, ξ_y	−50.0, −50.2
Linear chromaticity (corrected) ξ_x, ξ_y	+1.0, +1.0
Linear momentum compaction α_c	3.06×10^{-4}
Energy spread (natural) σ_δ	0.769×10^{-3}
Radiated power (bare lattice) U_0	363.8 keV/turn



First Turns, Stored Beam & Stacking

• First turn achieved with all magnets at nominal settings for 3 GeV according to magnetic measurement data and all ring correctors set to zero.

• Single dipole injection kicker at ~4 mrad, with manual corrector tweaking eventually reached 500 turns.

• After phasing in three cavities (delivering 15-20 kW each) could store beam.

• Reducing injection kicker voltage allowed to accumulate 4.3 mA; after relative phasing (maximize measured f_s) increased stored beam current and injection rate.

BPM Offsets & Orbit Correction

• BPM offsets determined with respect to neighboring sextupoles/octupoles (trim windings in upright quad mode).

• Checked BPM offsets over months in terms of reproducibility, drift, temperature stability, current dependence, etc.

• Orbit correction to BPM offsets results in <1 µm (H) and <41 µm (V) rms orbit (fewer VCMs than BPMs ➞ introduced weighting across ID straights).

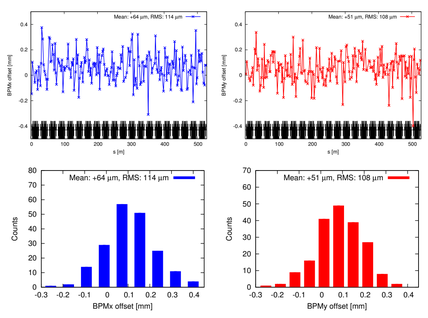


Figure 1: BPM offset results. Top: measured offsets downloaded to BPM units. Bottom: histogram of BPM offsets.

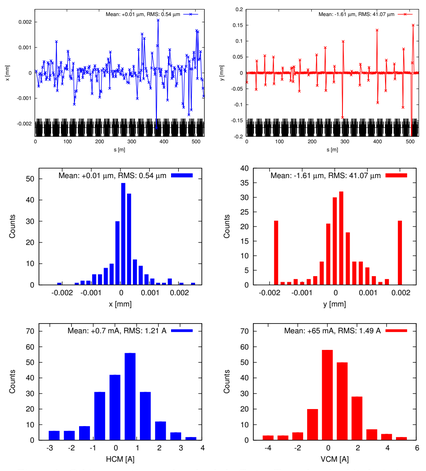


Figure 2: Orbit correction to downloaded offsets. Top: closed orbit deviations of corrected orbit. Middle: histogram of closed orbit deviations. Bottom: histogram of required corrector strengths.

Top-up Injection & Slow Orbit Feedback

• Reduced kicker strength and optimized injector RF chopper to achieve high capture efficiency ➞ raised injection rate from 0.5 Hz to 2 Hz (limitation to 2 Hz given by commissioning license).

• Started top-up injection in Nov 2016 ➞ strong increase of accumulated dose; allows control of filling pattern control.

• SOFB (relying on all 380 correctors) running since Nov 2016 at ~0.5 Hz (MML script) ➞ orbit stability across ID straights 200-400 nm rms.

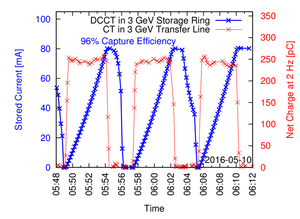


Figure 3: Current in storage ring (blue) and injected charge per shot from linac transfer line (red) showing increased capture efficiency as commissioning progressed.

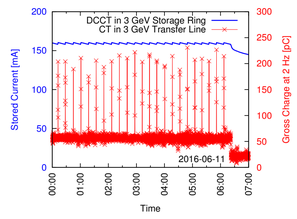


Figure 4: Stored current (blue) and injected charge per shot from linac transfer line (red) during top-up operation.

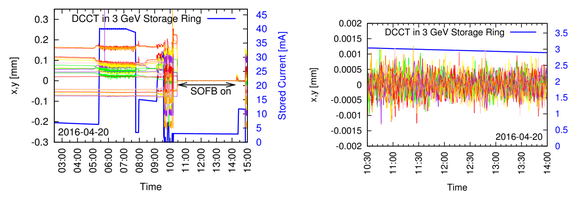


Figure 5: Position readings from BPMs in ID straights. Left: results over a 12-hour period showing drift during decaying beam, jitter during top-up injection, and stable orbit while the SOFB is running. Right: magnified view over the period while the SOFB is running.

Linear Optics from Closed Orbits (LOCO)

• Symmetrization/balancing of optics through LOCO using BPMs, correctors, and all independent power supplies for upright quadrupole gradients (no skew corrections yet).

• Largest required gradient change remained below 1.5%; individual quad shunting possible later.

• After several iterations, difference between measured and model ORM as low as 0.7 µm rms.

Table 2: Parameters for LOCO fitting (w/o skew quad terms).

Parameter type	No. of paremeters
BPM gains (H + V)	189 + 189
BPM coupling factors (H + V)	189 + 189
Corrector strengths (H + V)	200 + 179
Corrector coupling factors (H + V)	200 + 179
Dipole gradients (PFSs)	2
Quadrupole gradients	20 × 2 + 20 × 2 + 2

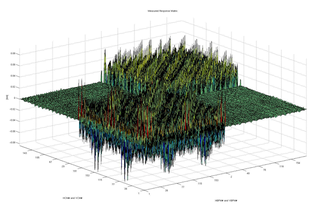


Figure 6: Plot of measured ORM.

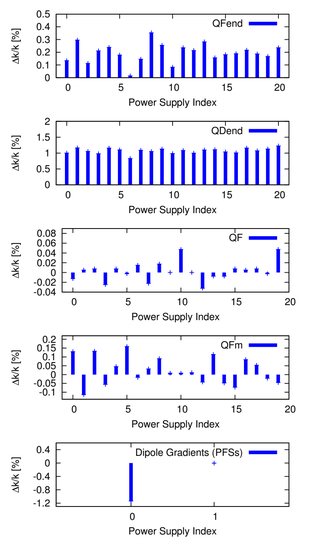


Figure 7: Required changes to quadrupole gradients according to results of the uncoupled LOCO fit.

Optics Tuning, Chromaticity & Dynamic Acceptance

• After LOCO adjustments tunes match design to better than 0.01, beta beating is ~1% rms in both planes, horizontal dispersion beating suppressed.

• Spurious vertical dispersion and betatron coupling remain to be corrected (skew quad correction).

• IVU FF tables recorded down to 4.5 mm gap; at closed gaps ~1 um rms orbit recorded (with SOFB); local and global optics correction for IVUs remain to be implemented (no signs of beta beating observed so far).

• Linear chromaticities corrected to +1 in both planes; 2nd order terms agree reasonably to design.

• Scraper measurements have revealed lifetime contributions and effective pressures; together with local beta function measurements overall machine acceptance has been determined ➞ 7.0 mm mrad in H & 2.5 mm mrad in V agree very well with tracking study results.

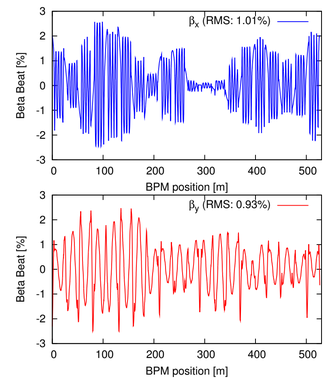


Figure 8: Remaining beta beat after downloading results of the LOCO fit to the quad power supplies: horizontal (top) and vertical (bottom).

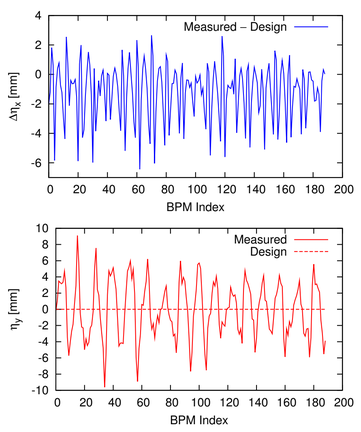


Figure 9: Horizontal dispersion beating (top) and spurious vertical dispersion (bottom) after downloading results of LOCO fitting to the quad power supplies.

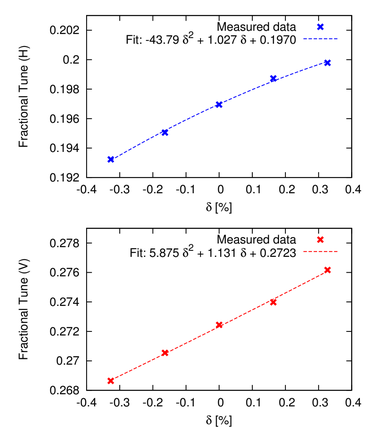


Figure 10: Measured chromaticity: horizontal (top) and vertical (bottom).

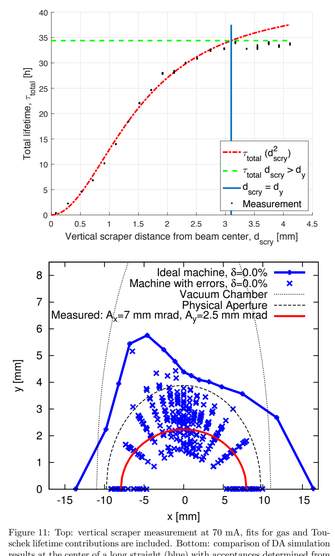


Figure 11: Top: vertical scraper measurement at 70 mA, fits for gas and Touschek lifetime contributions are included. Bottom: comparison of DA simulation results at the center of a long straight (blue) with acceptances determined from scraper measurements (red).

Emittance & Lifetime

• First measurements on the first diagnostics beamline have revealed 339±30 pm rad H emittance and 16±1 pm rad V emittance (κ = 4.7%).

• As commissioning progressed integrated lifetime has increased from 0.3 A h to 2–3 A h (pressure improving as accumulated dose increases, tuning of the HCs).

MAX IV Facility → http://www.maxiv.lu.se/

WEPAB075, IPAC'17, Copenhagen, DENMARK, May 14–19, 2017

†) New address: Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA, SCLeemann@lbl.gov