Summary of LERD at LER2016
low emittance ring design

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and
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Low Emittance Ring Design

5 sessions – 25 talks; topics:

Commissioning/operation results (MAX IV, NSLS-II)

Updates/design progress (SIRIUS, SOLEIL, APS-U, CHESS, Diamond II, ALS U, HEPS, ELETTRA2.0, DIAMOND II, Spring-8, Lit-J)

Optimisation tools (Huang, Ehrlichmann, Hua-Yu, …)

Analysis of performance (ESRF optics, ESRF-EBS lifetime, Spring-8 injection, Top-up injection in HEPS, V emittance APS, crab cavities at SPEARIII)

https://indico.cern.ch/event/574973/
MAX IV commissioning (S. Leemann)

3 GeV Storage Ring Commissioning (cont.)

- Storage Ring DCCT
- Top-up @ 160 mA over night
- Top-up shots from linac
- Transfer Line CT
- Injection kicker left on
- Decaying beam
- Linac modulator K02 tripped

Simon C. Leemann
6th Low Emittance Rings Workshop, SOLEIL, October 26–28, 2016
MAX IV commissioning (S. Leemann)

3 GeV Storage Ring Commissioning (cont.)

• First two IVUs installed during Feb 2016 shutdown
  – Hitachi, 18 mm period, 4.2 mm magnetic gap, 2 m length, 1.3 T peak field
  – for BioMAX and NanoMAX beamlines

• ID, FE & BL commissioning started Apr 2016

[Images of NanoMAX and BioMAX commissioning results]
Sirius progress (F. E. De Sa)

Sirius building (Aug. 2016)

Budget
- Accelerators: 94 M €
- 13 beamlines: 133 M €
- Building: 200 M €
- Human Res: 53 M €
- Total: 480 M €

Schedule
- Jan.2015: start of building construction
- Sep.2017: start of machine installation
- Aug.2018: start of SR commissioning
- Jan.2019: phase 1 operation (20 mA, NCC)
- Jul.2019: phase 2 operation (100 mA, SCC)
Sirius progress Magnets (F. E. De Sa)

Partnership LNLS/WEG

LNLS: simulation, design & magnetic measurement

- 15,000 employees in this plant
- 50,000 electric motors/day
Sirius progress Magnets (F. E. De Sa)

Magnets production

- A strategic decision for the production of Sirius magnets was to start with the booster magnets with tolerance requirements approaching the ones required for the storage ring.
- Delivery of all booster magnets will be completed by Dec. 2016.
Sirius progress Vacuum (F. E. De Sa)

Fully NEG coated strategy with copper chamber

- Copper Chamber
- Cooling Tube
- ø 24mm
- Low impedance flange
- Zero gap copper seal
- Pumping Station
  - Crotch absorber, Ion pump, NEG cartridge, Vacuum gauges
- BPM Flanges
  - RF shielding
- BPM
- Dipole chamber
  - ID radiation extraction
- Keyhole design
- 0.3 mm SS sector
  - For fast orbit correctors
## ALS-U Timeline and Status

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
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<tr>
<td>Jul 2013</td>
<td>BESAC Subcommittee on Future X-ray Science: “The Office of Basic Energy Sciences should ensure that U.S. storage ring x-ray sources reclaim their world leadership position.”</td>
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<td>Since FY14</td>
<td>Received funding from LBNL for R&amp;D as well as pre-project development. In FY16 received funding from BES for Research and Development for the Advanced Light Source Upgrade</td>
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<td>Jun 2016</td>
<td>BESAC Prioritization Panel grades ALS-U as “Absolutely Central” to contribute to world leading science and as “Ready to Initiate Construction”</td>
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<tr>
<td>Sep 2016</td>
<td>ALS-U receives approval of Mission Need (CD-0) from DOE/BES</td>
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ALS-U lattice design (M. Venturini)

8BA DA is superior to 9BA's in spite of larger chromaticites

**not to scale**
SOLEIL plan (A. Nadji)

Lattice based on 7BA (à la ESRF) and 6BA (à la Diamond)

\[ \varepsilon_x = 250 \text{ pm.rad} \quad \xi_{x0} = -84 \quad \xi_{z0} = -77 \]
Strategy

☐ The Final requirements should derive from future science goals.

☐ Target date: 2025

☐ First directions:
  • Higher brilliance and coherence fraction.
  • Short « intense » pulses.
ELETTRA 2.0 plan (E. Karantzoulis)

2 principal configurations
Physical interference control

Old concrete support bases will not be reused, new girders will be constructed, propose 3D because magnets are thin.
Online dynamics optimisation (X. Huang)

Coupling correction experiments on SPEAR3 with RCDS

Using loss rate (normalized) as objective

Using $\sigma_y$ from pinhole camera as objective

Beam loss rate is monitored to see if beam current changes (no fitting). Noise signals were taken at 500 mA.

Initially all 13 skew quadrupoles were off. At 500 mA, the best was 4.6 hrs. This was better than skew quad correction (5.2 hrs).

Skew quad strength

Huang, 10/26/2016, at LER2016
Applications of RCDS on real-life problems

• SPEAR3
  - Kicker bump matching
  - Transport line optics
  - Transport line steering
  - GTL steering and optics
  - Injection efficiency w/ sextupoles  
    X. Huang, J. Safranek, PRSTAB 18, 084001 (2015)

• LCLS
  - Undulator taper optimization  
    J. Wu, K. Fang, X. Huang, 2014-2016

• BEPC-II luminosity optimization
  - Steering and coupling  
  - Interaction point beta

• ESRF
  - beam lifetime w/ sextupoles
  - Injection steering  
    S. M. Liuzzo, et al, IPAC’16, THPMR015

X. Huang, 10/26/2016, at LER2016
Two frequency crab cavity scheme (X. Huang)

A. Zholents, NIMA 798, 111 (2015)

The two-frequency crab cavity scheme

Two frequencies:
\[ f_1 = nf_0, \]
\[ f_2 = \left(n + \frac{1}{2}\right)f_0 \]

Half of the buckets are tilted, the other half are un-affected.

Advantages of the new scheme:
(1) Short pulses are available all around the ring.
(2) No strict phase advance requirement for lattices.
(3) Crab cavities occupy only one straight section (and only one cryostat for SRF)
(4) Both cavities contribute to tilting (less total deflecting voltage required)
(5) Beamlines can easily switch between short pulse mode and regular mode.
V. VACUUM LOSSES AND CONDITIONING

- Vacuum losses will be dominant over Touschek losses during the commissioning and conditioning of the new machine,
- Following a similar method as for Touschek scattering, scattered electrons can be generated and tracked after colliding with residual gas atoms,
- It includes a detailed pressure profile along the ring, as well as a custom gas composition,
- The losses are determined by
  - the vertical angle acceptance for elastic collisions,
  - by the negative side of the momentum acceptance for the inelastic collisions.

![Loss map, Calculated lifetime = 57.6166 h]

- $\tau = 367.6955\text{hrs}$
- $\tau = 377.2889\text{hrs}$
- $\tau = 83.4307\text{hrs}$

ESRF-I, multi-bunch
HEPS Injection studies (Z. Duan)

Two RF systems 3rd HC – play with amplitude and phase to manipulate RF buckets for on axis injection and operation. IBS induced parameter changed at injection (Top-Up)

Longitudinal dynamics of a double-RF system

\[
H(\phi, \delta; t) = \frac{h_f \omega_0 \eta}{2} \delta^2 + \frac{e \omega_0}{\pi E_b \beta^2} \left[ \sum_{i=1}^{N_f} V_f^i \cos(\phi + \phi_f^i) + \frac{h_f}{h_h} \sum_{j=1}^{N_h} V_h^j \cos(h_h \phi + \phi_h^j) + \phi \frac{U_0}{e} \right]
\]

- Fundamental RF system: 166.6MHz, Nf=4
- 3rd harmonic RF system: 499.8MHz, Nh=2
- Same settings for cavities with the same frequency
  \[ V_f = 4V_f^i, \phi_f = \phi_f^i, V_h = 2V_h^i, \phi_h = \phi_h^i \]
- 4 free variables \((V_f, \phi_f, V_h, \phi_h)\)
- One constraint to fix longitudinal phase of circulating beam relative to the cavities
  \[ V_f \sin \phi_f + V_h \sin \phi_h = U_0 \]
- Longitudinal dynamics can be solved to achieve required RF acceptance, in particular, evolution between operation and injection modes.
Semi-analytical approach to nonlinear dynamics (L. Hua Yu)

Write one turn map of Taylor expansion as square matrix

Simplest example of nonlinear map:

\[ x = x_0 \cos \mu + p_0 \sin \mu + \epsilon x_0^2 \sin \mu, \]
\[ p = -x_0 \sin \mu + p_0 \cos \mu + \epsilon x_0^2 \cos \mu. \]

Use \( z = x - ip \) and \( z^* = x + ip \)

\[
\begin{align*}
  z &= e^{i\mu} z_0 - \frac{i}{4} \epsilon e^{i\mu} z_0^2 - \frac{i}{2} \epsilon e^{i\mu} z_0 z_0^* - \frac{i}{4} \epsilon e^{i\mu} z_0^*^2 \\
  z^* &= e^{-i\mu} z_0^* + \frac{i}{4} \epsilon e^{-i\mu} z_0^2 + \frac{i}{2} \epsilon e^{-i\mu} z_0 z_0^* + \frac{i}{4} \epsilon e^{-i\mu} z_0^*^2 \\
  z^2 &= e^{2i\mu} z_0^2 - \frac{i}{2} \epsilon e^{2i\mu} z_0 z_0^* + i \epsilon e^{2i\mu} z_0 z_0^2 - \frac{i}{2} \epsilon e^{2i\mu} z_0^* z_0^2 \\
  z z^* &= z_0 z_0^* + \frac{i}{4} \epsilon z_0^3 + \frac{i}{4} \epsilon z_0 z_0^2 - \frac{i}{4} \epsilon z_0^2 z_0^* - \frac{i}{4} \epsilon z_0^3 \\
  z^*^2 &= e^{-2i\mu} z_0^*^2 + i \epsilon e^{-2i\mu} z_0 z_0^2 + i \epsilon e^{-2i\mu} z_0 z_0^* - \frac{i}{2} \epsilon e^{-2i\mu} z_0^* z_0^2 \\
  z^3 &= e^{3i\mu} z_0^3 \\
  \vdots \\
  z^*^3 &= e^{-3i\mu} z_0^3 \\
  \tilde{Z} &= (1, z, z^*, z^2, z z^*, z^*^2, z^3, z^2 z^*, z z^* z^*, z^*^3). \\
\end{align*}
\]

\[ Z = M Z_0, \]

Fast computation of nonlinear dynamic quantities (detuning, action variations, ...)
Conclusions

Many excellent talks (cannot fit in this short summary)

MAX IV well in its commissioning, SIRIUS and ESRF-EBS being built

Many projects in design phase. Slowly but steadily gaining approval

APS–U CD1 February 16
ALS–U CD0 September 16

Optimisation!

from lattice design to operation

LERD topical workshop in Lund 1-2 December

https://indico.maxiv.lu.se/event/193/
The 2nd Workshop on Low Emittance Ring Lattice Design will be held from 1-2 December 2016, organized jointly by Paul Scherrer Institut and MAX IV Laboratory, hosted by MAX IV. The workshop will focus on the following topics:

- Design Concepts
- Design Tools / Tools for Non-linear Optimization
- Error Sensitivity / Alignment Strategies / Correction Schemes
- Influence of Collective Effects on Designs

The sessions will start with tutorial like educational talks which prepare the floor for short contributions on particular aspects followed by discussions. All participants are invited to propose contributions to the organizing committee. Furthermore, we wish to bring your attention to the XXIV European Synchrotron Light Source Workshop, which is organized in close connection to this workshop. EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453.

Contact: Michael Böge

Thank you!