Automated optimization of the European XFEL performance with OCELOT

Sergey Tomin

Machine Learning Applications for Particle Accelerators

SLAC, 28.02.2018

Outline

Introduction

■ FEL tuning: Fundamentally important for operation!

■ However: lengthy and tedious when done manually.

■ Human expertise is required for top performance **but:** automatic tuning helps a lot

■ What do we need?

　■ Tools for automatic optimization (model-independent and model-dependent).

　■ Some parameters/correlations are hidden, understanding of the machine and physics behind it is crucial for getting even better performance:

　　► Online model

　　► Machine learning

European XFEL

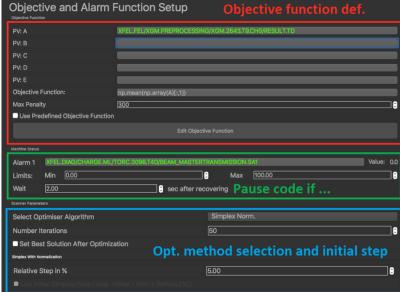# OCELOT Generic optimizer

- OCELOT project
  - Started as simulation project (Undulator radiation, FEL) at European XFEL.
    Agapov et al., NIM A. 768 2014
  - Beam dynamics module was developed (linear optics, collective effects, second order effects, optim. techniques).
    S.Tomin et al. WEPAB031
  - Everything in **Python**. Focus on simplicity. Implement only physics
  - Turned into more on-line control-oriented development.
    arXiv:1704.02335
  - Open source (On GitHub **https://github.com/ocelot-collab/ocelot**)
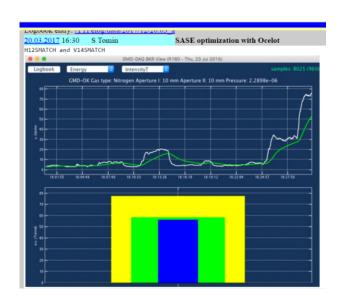
European XFEL

Generic optimizer

- 2015: First demonstration at FLASH. *I. Agapov et al. TUPWA037 IPAC15*

- 2017: universal tool (generic optimizer) for European XFEL commissioning

- Deployed for European XFEL and FLASH.

European XFEL

Generic optimizer: Use cases

■ Several different customized variants of the optimizer were used only a few times for different tasks.

■ Examples for earlier customized setups:

  ■ Minimization of beam losses while keeping a reasonable orbit in the main dump beamline.

  ■ Orbit distortion compensation with air coils in an undulator section.

  ■ Minimization of HOM (higher order mode) signal in an accelerator module (FLASH).

  ■ SASE maximization (FLASH).

  ■ Dispersion correction (FLASH)
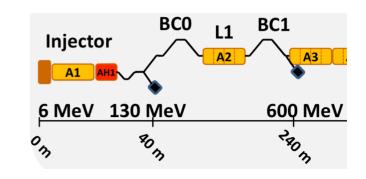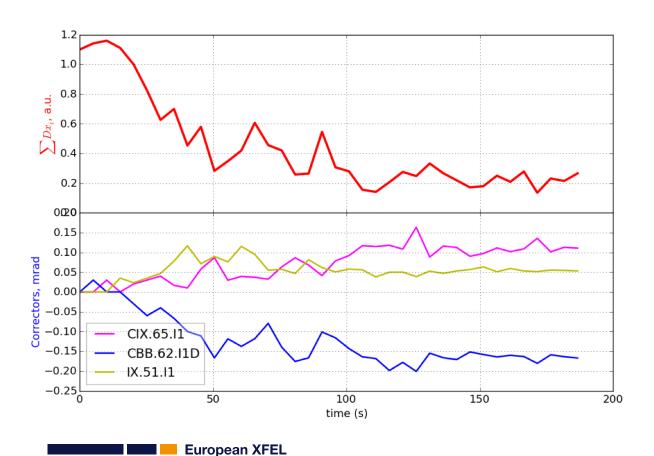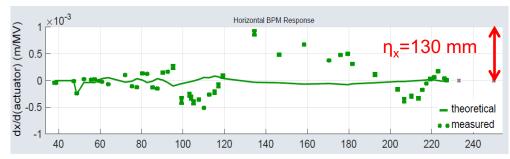

European XFEL

Generic optimizer: local dispersion correction

Horizontal spurious dispersion correction with 3 corrector magnets.
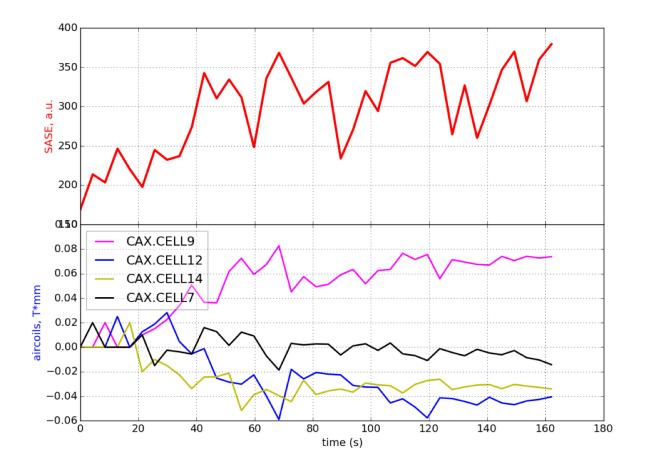

Before correction

After correction

Laser Heater chicane

Generic optimizer: SASE optimization

■ Air coils between the undulator cells were used to optimize the SASE signal

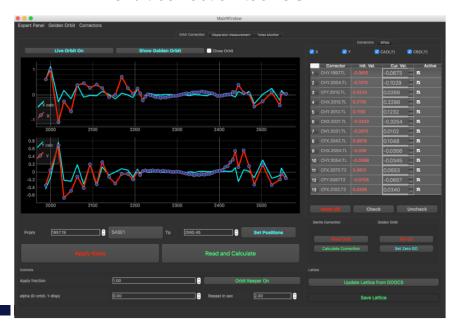■ Up to 6 air coils are typically used at the same time.

OCELOT orbit correction tool with adaptive feedback

European XFEL

Orbit correction tool with adaptive feedback.

- OCELOT orbit correction is the standard tool for orbit correction (using SVD algorithm).

- The adaptive feedback is a part of the orbit correction tool. It is used currently for an continuous orbit correction upstream the undulator to optimize the SASE pulse energy.
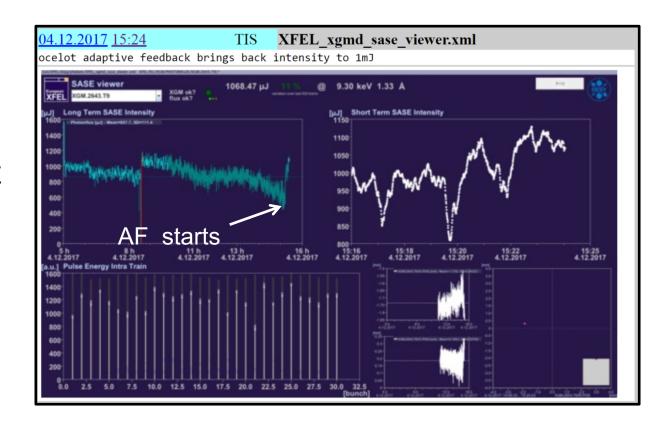
Orbit correction tool GUI

Adaptive Feedback GUI

Adaptive feedback (SASE1)

■ Algorithm of Adaptive Feedback*

■ Shot-to-shot collection of orbits (~ 300 - 700) and the corresponding SASE pulse energy.

■ Sorting orbits according to SASE energy.

■ Taking 10-20% of the orbit with highest SASE and calculating new golden orbit for the feedback.
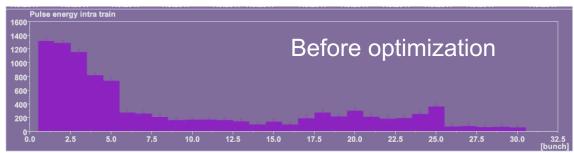

*Idea from: G. Gaio, M. Lonza, Automatic FEL Optimization at FERMI, Proc. of ICALEPCS2015
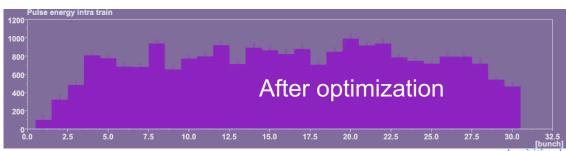
Adaptive feedback (SASE1)

■ Optimization of the orbit upstream the undulator. Only first three bunches were lasing before optimization. The IBFB was not commissioned at that time. Thus not all bunches were on the same orbit.

■ The adaptive feedback optimizes by default the averaged SASE signal over all bunches in one bunch train. However, it is also possible to optimize for dedicated bunches if required.

■ The lasing of the first bunches was suppressed but all following bunches contributed to the SASE level after the optimization with the adaptive feedback.

During User Run (November 20 - December 5) Adaptive feedback was used 233 times and total working time Σ 89 hours

Before optimization

After optimization

European XFEL
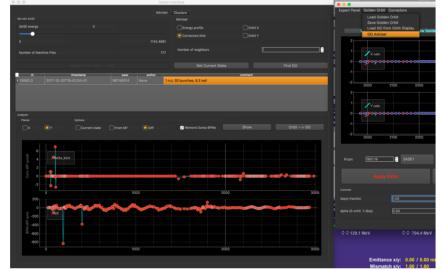
Machine Learning at European XFEL

Golden Orbit Adviser

- Recently we introduced to the Ocelot orbit correction tool a "Golden orbit adviser" (in test mode).

- The idea is to find the machine file in the database that is as close as possible to the current machine setup.

- For instance, you can select as a reference vector the corrector kicks (or beam orbit in X/Y plane) and ML method (Nearest Neighbors) will find the machine file with the corrector kicks (or orbit) closest to the current conditions.

Virtual XFEL with SASE signal for optimization methods studies (plans)

- Virtual XFEL* is environment for testing high level controls and applications

- Virtual XFEL has a physics server to simulate e-orbit with 10 Hz rep rate, what allows physics experiments to some extent (orbit correction, BBA).

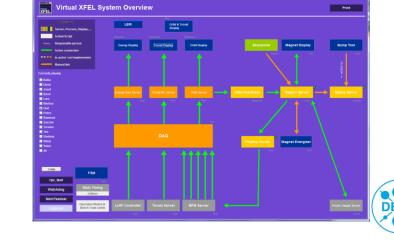- Idea is to extend VEXFEL capabilities to generate SASE signal for studies of optimization and automatics tuning methods
  - Collecting data during real machine setup, SASE tuning
  - Training NN
  - Using NN to generate SASE signal in VEXFEL

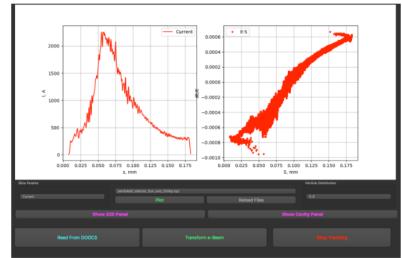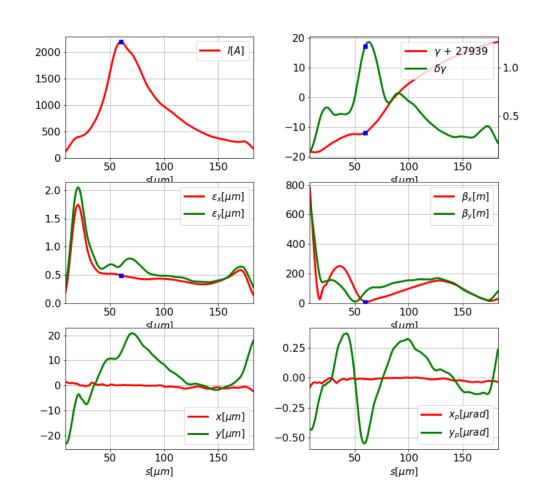*R. Kammering et al, The Virtual European XFEL Accelrator, TUD3O04, ICALEPCS2015

European XFEL

S2e simulations in control room
Online model

OCELOT toolkit: S2E in control room

- Reading quads and cavities settings and measured beta-functions

- Tracking 200000 particles with CSR, SC, wakes through all machine up to undulator section

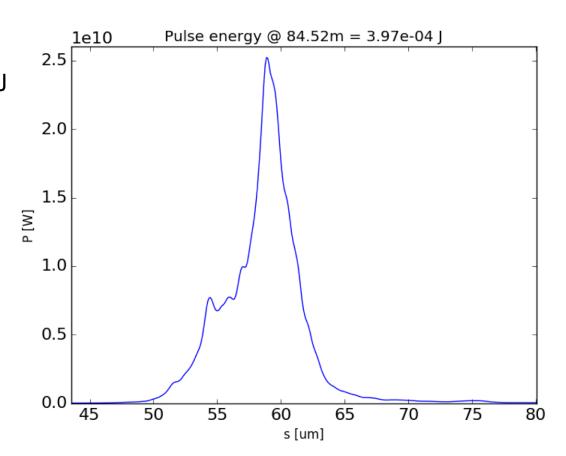- Total time calculation 20 mins

Coauthors: M.Dohlus, I.Zagorodnov

OCELOT toolkit: S2E in control room
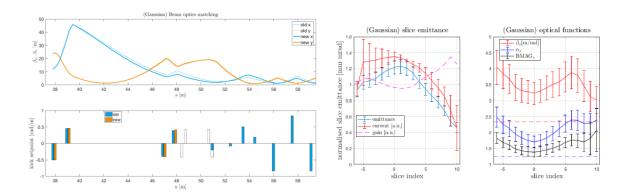
■ FEL power Estimator (Ming Xie parametrization). – 0.4 mJ

■ In reality, we had 1 mJ with nonlinear undulator tapering

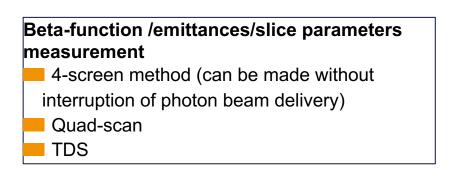■ Genesis can be used as well, however infrastructure to cluster is needed

Authors: G.Geloni, S.Serkez

European XFEL

Can we improve online model?

Beta-function /emittances/slice parameters measurement
- 4-screen method (can be made without interruption of photon beam delivery)
- Quad-scan
- TDS

Courtesy by M.Scholz, B. Beutner

Single particle optics measurements
- Kick the beam by two correctors
- fitting elements of TM
- Track twiss parameters through machine using design or measured beta-function
- Time measurement ~ 2 mins
- TM can be used in other tools

European XFEL

Courtesy by F.Brinker

Conclusion

- OCELOT optimization is a part of the daily European XFEL operation
  - merging the XFEL and SLAC optimizer versions (create clear API for addition of Opt.Method)
  - Addition new methods

- R&D of the accelerator online model and S2E simulations (including FEL process) in control room:
  - Reduce calculation time in 10 - 20 times (from 20 mins to …) optimize algorithms, using GPU/clusters…
  - Connect online model to reality → measurement / control / simulations

- Machine Learning in operation and optimization
  - infrastructure is needed (DBs, events recognition)

European XFEL

…so, thanks to all the people who contributed to this work (commissioning teams, colleagues etc)

…and thank you for your attention!

European XFEL