Diagnosing an In-Vacuum Undulator in the ALS Storage Ring

D. Bertwistle, J. Dickert, T. Hellert, M. Kritscher, S.C. Leemann, F. Sannibale, T. Scarvie, C. Steier, S. Trovati, E. Wallén

Lawrence Berkeley National Laboratory, Berkeley, CA. USA

Abstract

The Advanced Light Source (ALS) has an in-vacuum undulator named “LEDA”. It was installed in 2019 and provides high-brightness, high-energy photons for the ALS macromolecular crystallography beamline, GEMINI. The undulator is a hybrid design with a minimum gap of 4.3 mm, a magnetic period of 15 mm, and a photon energy range of 5–19 keV. When the device was commissioned in the ALS storage ring, it had a negligible impact on ring operations. Recently, there has been a measured degradation in storage ring performance and an increase in radiation at the beamline, both correlated with the LEDA gap. Prior to conducting an invasive magnetic measurement, we performed a suite of beam-based measurements to characterize LEDA. Herein, we detail these measurements and share them with the accelerator community, who may find them useful when encountering similar challenges.

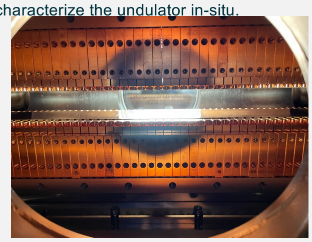
Background

GEMINI was commissioned, with beam, at the end of 2020 to a gap of 4.5 mm. At first light, the radiation levels were slightly higher than expected but still below the regulatory limits and remained constant for over a year.

Since 2021 LEDA’s gap-dependent tune-shifts have changed. This was accompanied by an increase in radiation dose measured on the experimental floor at the GEMINI beamline, increasing injection losses, and a reduction in ring lifetime.

LEDA has been opened and CuNi liner, RF fingers, and transition pieces were found to be in excellent condition.

Thus, a beam-based measurement campaign was launched to better characterize the undulator in-situ.

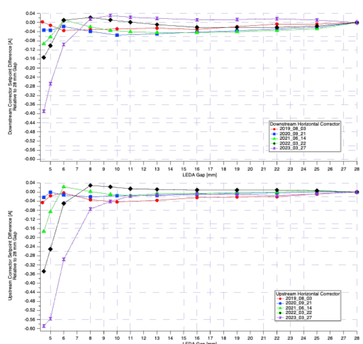


LEDA Cu/Ni liner inspection

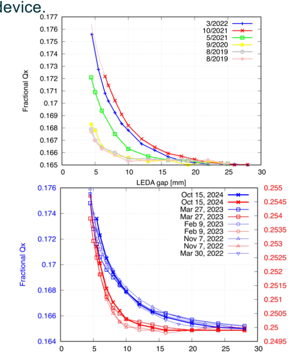
LEDA RF transitions.

Historical Data

Feedforward look-up tables can track changes in the integrated magnetic field. Thus, capturing changes in the undulator termination magnets and/or changes in the magnetic field periodicity field over time. Frequent measurements of gap dependent tune-shifts can indicate a change in the undulator focusing or impedance. The authors emphasize the utility of storing and managing this data over the lifetime of the insertion device.



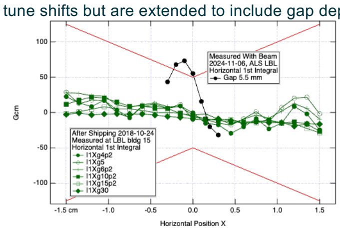
LEDA dipole corrector look-up tables vs. gap vs. year

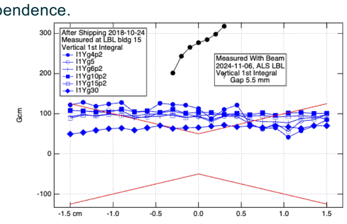


LEDA tune-shift vs. gap vs. year

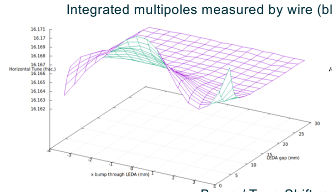
Beam Based Multipole and Tune Shift Measurements

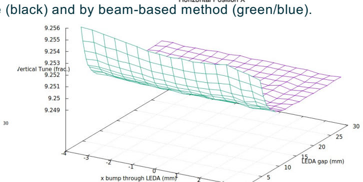
At maximum LEDA gap we stepwise add either a vertical or horizontal parallel bump through the straight. We then closed the gap to 5.5 mm and observe the change in corrector strength at the flanking combined function corrector magnets. For each applied bump we obtain an effective 1st field integral for LEDA. The same bump/measure methodology was used for the tune shifts but are extended to include gap dependence.





Integrated multipoles measured by wire (black) and by beam-based method (green/blue).

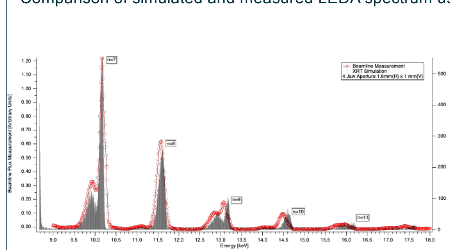




Bump / Tune Shift measurements vs. gap.

Beamline Spectrum Measurement

Comparison of simulated and measured LEDA spectrum using ALS electron beam parameters.

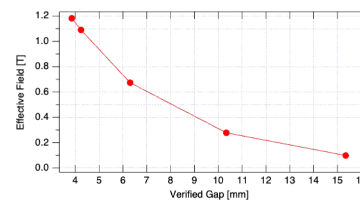


LEDA flux measured and simulated (XRayTracer).

Modelling the GEMINI beamline consists of a series of beam defining apertures, a double crystal monochromoter, and an Al foil flux monitor immediately after the monochromoter. In this measurement the LEDA gap was set to 6.0 mm. The limiting aperture was 1.6 mm (H) x 1 mm (V) and approximately 16235 mm from the LEA centre. The flux monitor was 19434 mm from the LEDA centre.

Undulator Parameters

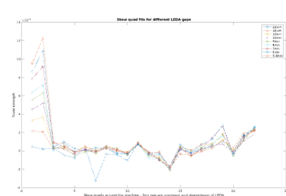
LEDA was designed for a protein crystallography beamline that requires high photon energies with a 1.9 GeV electron beam. Thus, LEDA has a short period of 15 mm and is of the in-vacuum hybrid type to achieve a high effective magnetic field of 1.053 T (Fig. 3) at a minimum gap of 4.386 mm and practically operate on a high harmonic number. It has 131 periods and an overall magnetic material length of 1995.1 mm.



LEDA effective magnetic field vs. gap.

LOCO Measurements

We used LOCO measurements to understand if a previously absent gap dependent skew quadrupole is present in the machine optics of the undulator. We scripted LOCO measurements on the entire storage ring to enforce the desired 2% machine coupling for various LEDA gaps. In this case the flanking combined function magnet skew quadrupole coils were incorporated into the fit. The upstream/downstream skew quadrupoles flanking LEDA require relatively strong changes to maintain the coupling.



LOCO fit for LEDA gap dependent skew quad. compensation.

Conclusion

The LEDA beam-based measurements included integrated multipoles, tune shifts, LOCO fits, feedforward tables, radiation floor measurements, and x-ray spectra. The data suggest possible radiation damage. The year-to-year changes in the historic gap dependent feedforward tables and tune shift data highlight their utility as diagnostic tools. Finally, the measurements in this article make a compelling case to perform Hall probe and stretched wire bench measurements on LEDA.

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†bertwistle@lbl.gov

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ATAP ACCELERATOR TECHNOLOGY & APPLIED PHYSICS DIVISION