Beam Based Optimization and Machine Learning for Synchrotrons

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Abstract

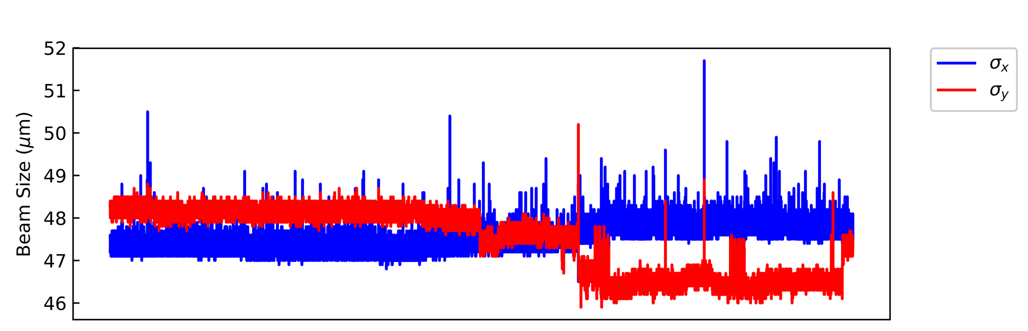
Synchrotron light sources, arguably among the most powerful tools of modern scientific discovery, are presently undergoing a major transformation to provide orders of magnitude higher brightness and transverse coherence enabling the most demanding experiments. In these experiments, overall source stability will soon be limited by achievable levels of electron beam size stability, presently on the order of several microns, which is still 1–2 orders of magnitude larger than already demonstrated stability of source position and current. We now demonstrate for the first time how application of machine learning allows for a physics- and model-independent stabilization of source size relying only on previously existing instrumentation, resulting in source size stability as low as 0.2 μm (0.4%) rms

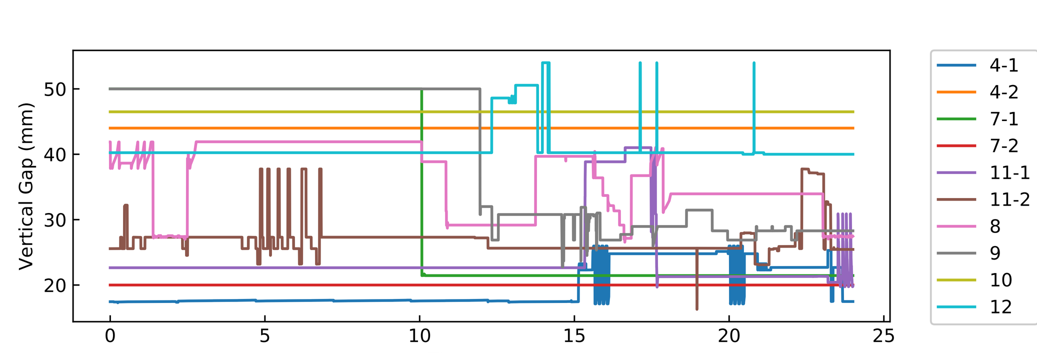
1. Introduction

- Overall source stability relies on maintaining constant source position/angle and intensity (beam size and current).
- Source stability on the sub-micron level is routinely achieved through orbit feedback (FB) and ID feed-forwards (FF).
- Top-off injection maintains constant current on the sub-percent level over the entire user time.
- Source size stability is finally achieved through optics corrections: both systematic (ID FF) and random error corrections (FB) are routinely employed.
- ID gap/phase compensation is based on lookup tables for skew quadrupole corrections; recording these tables takes large amounts of dedicated machine time.
- Due to machine drifts (temperature and ground sediment changes), ID compensation quality deteriorates over time.
- Machine Learning offers a solution to this problem that is stable over time and requires little dedicated machine time.

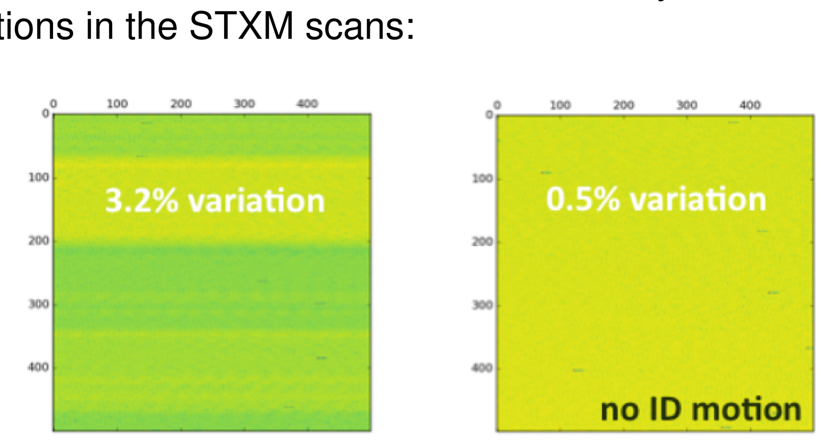
2. Source Size Stability

- In addition to orbit FBs, the ALS employs local optics corrections to compensate for perturbations from ID gap/phase motion: local and global quadrupole and skew quadrupole corrections.
- At 2 GeV the ALS is susceptible to ID focusing and skew errors.
- Local ID FFs are used to correct systematic focusing and skew quadrupole errors resulting from ID motion.
- These ID FF tables are, however, imperfect and their performance deteriorates with time as the machine drifts.
- Over a 24-hour user shift we see multiple steps of the vertical beam size despite all orbit FBs and ID FFs are running. The cause of these steps are ID gap/phase changes.



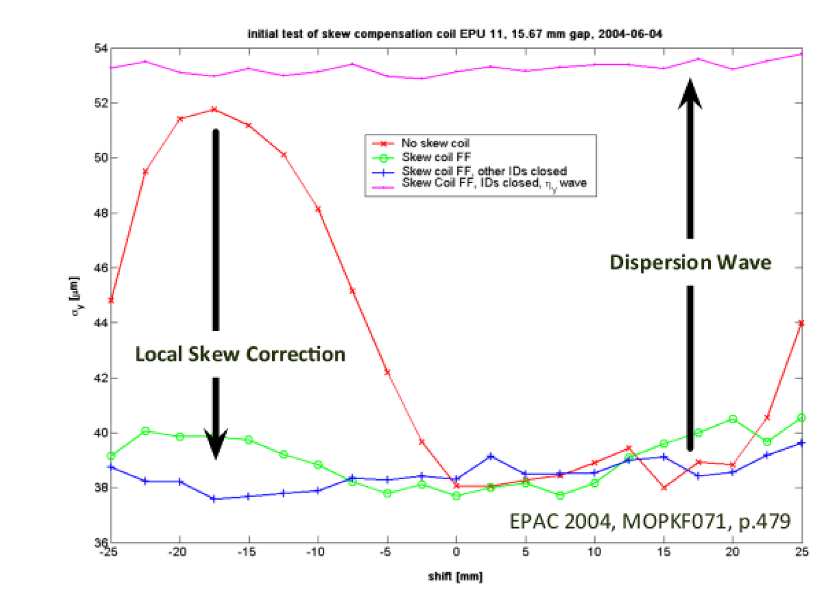


- A good example is ALS beam 5.3.2.2 (STXM) where variations of the vertical source translate directly to intensity fluctuations in the STXM scans:



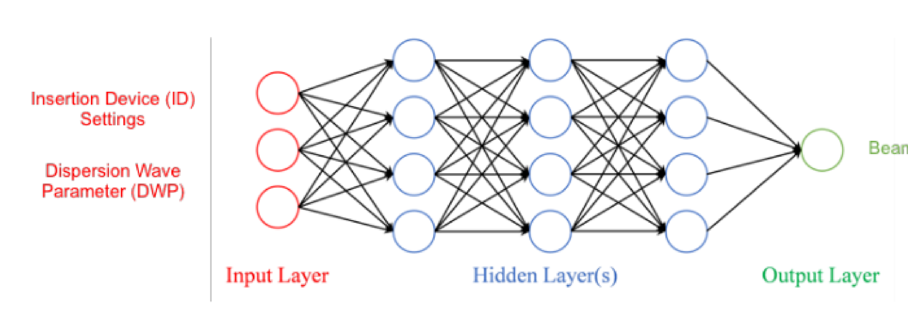
3. Vertical Beam Size & Dispersion Wave

- ALS diagnostic beamline 3.1 can be used to measure vertical beam size with high accuracy at 5 Hz.
- Vertical beam size at source points is determined by a dispersion wave (which excited vertical emittance, a global conserved quantity) relying on 32 skew quadrupoles.



4. Neural Network & Training

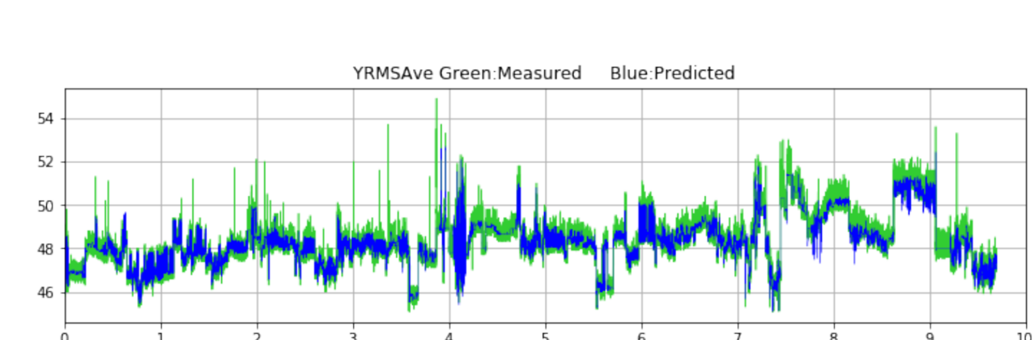
- A neural network (NN) can deliver accurate predictions for beam size as a function of ID gap/phase configurations and skew quadrupole settings described by the dispersion wave parameter (DWP):

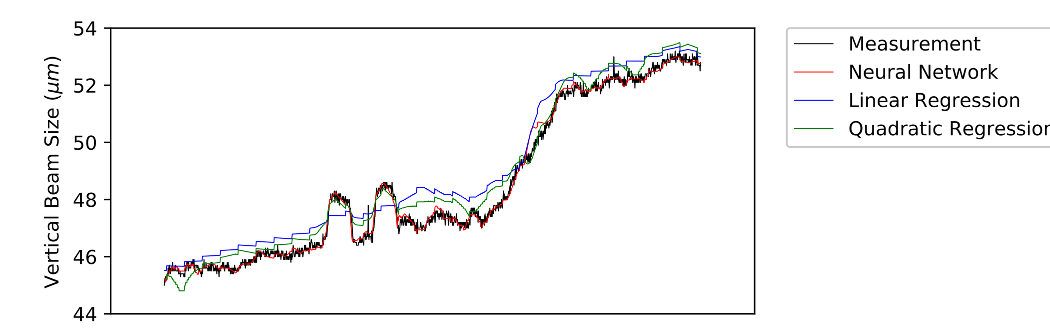


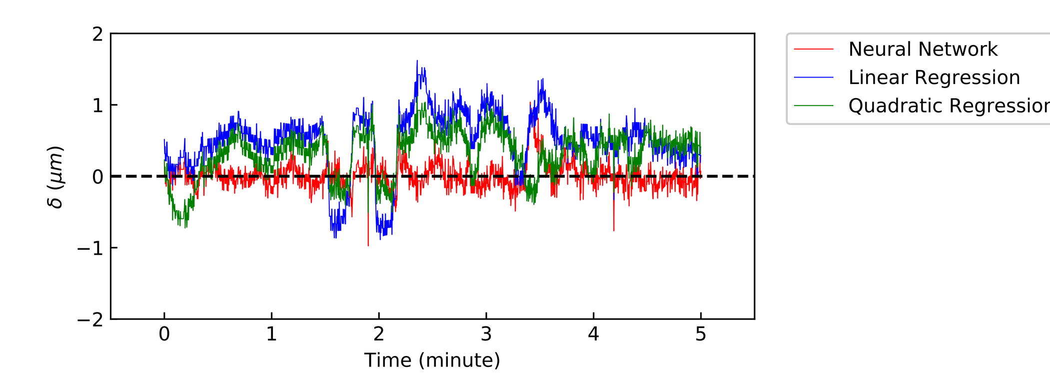
- The NN is trained using 10 Hz data including all ID and skew configurations as well as the beam sizes as measured at the diagnostic beamline (total of 23 parameters total).
- This training data can be acquired during a machine physics shift where we continuously scan ID configurations to mimic user operations while changing the vertical beam size.
- The entire training time takes on the order of minutes.
- We also compared NN with both linear and quadratic regression algorithms.

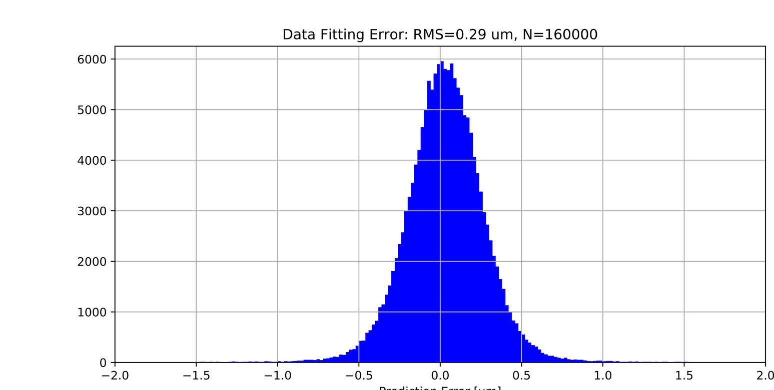
5. Machine Learning Results

- Simulations using user operations data showed that the predictions of such a NN could be very accurate.
- The residuals are on a sub-percent level.

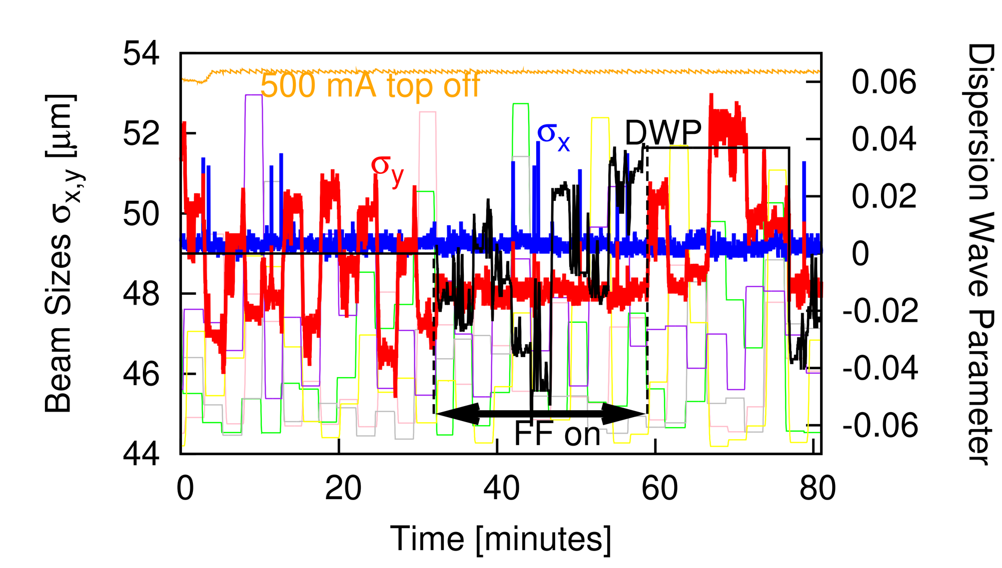




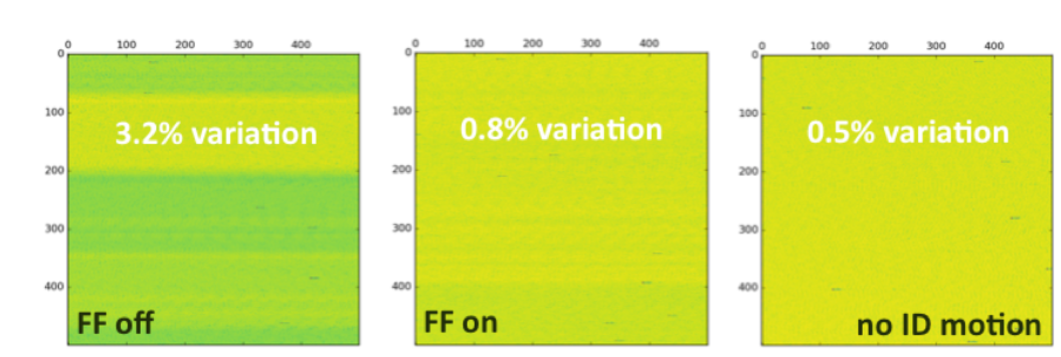




- The NN is fed current ID configurations along ith many possible skew quadrupole settings at 3 Hz. The predictions are expected beam sizes for each setting, obtaining the the required skew-quadrupole configuration, and then downloading the setting to the power supplies.
- Tests have shown a large increase in beam size stability.



The sensitive 5.3.2.2 STXM beamline saw a 4-fold reduction in RMS intensity fluctuation when the NN-based FF was running.



6. Discussion

- With successful stabilization confirmed at the most sensitive beamline, the NN-based FF was put into operation during user shifts.
- Over the course of many days the NN-based FF ran successfully achieving sub-percent level RMS stability of the vertical beam size in ALS without manual intervention.
- Online retraining will use a mix of collected original training data plus new user-ops data.
- Confirmed RMS stability was further improved over extended periods of time without requiring any additional dedicated machine time.

Acknowledgments

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