ORBIT IMPROVEMENTS AT THE CANADIAN LIGHT SOURCE

T. Summers, D. Chabot, L. Dallin, M. Sigrist. Canadian Light Source, University of Saskatchewan, 101 Perimeter Road, Saskatoon, Saskatchewan, S7N 0X4, Canada

Abstract

Upgrades to the orbit control system at the Canadian Light Source (CLS) have resulted in increased beam stability and reproducibility. These upgrades include improving position information from the beam position monitors (BPMs) by modifying the data acquisition algorithm and switching to a real-time operating system. Beam motion has been reduced to an RMS deviation of less than 1 micron in both planes. Limiting the maximum corrector step has allowed the use of all singular values when inverting the BPM response matrix, resulting in much better orbit reproducibility. As well, improved lookup tables have been developed to compensate for the effects of changing undulator gaps and polarizations. Presently, work is underway to develop fast orbit correction with rates up to 100 Hz. Fast orbit correction will further reduce the residual perturbations caused by undulator activity and will allow fast ramping of superconducting wigglers.

ORBIT CONTROL OVERVIEW

The CLS storage ring lattice is a symmetric 12-cell double bend achromat [1]. For orbit monitoring and correction, each cell (figure 1) has 4 button monitors to measure horizontal and vertical beam position and 4 horizontal and 4 vertical steering dipole magnets.

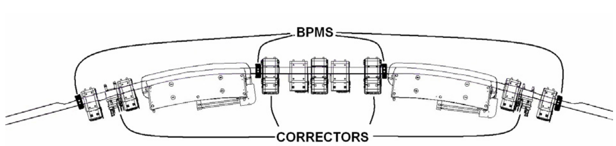

Figure 1: Schematic of cell showing locations of BPMs and correctors.

The orbit correctors magnets (OCMs) located between the dipoles are built into the sextupole magnets ('slow correctors') while the correctors on either side of the straight sections are single function ('fast correctors'). Setpoints for the slow corrector power supplies are sent from the control software along RS-232 serial cable while the fast corrector setpoints use fast VME based connections. Feedback for all OCMs is on RS-232.

The current top level orbit control interface 'CLSORB' is built on the Accelerator Toolbox package [2] and Matlab Channel Access libraries to connect to the EPICS control level. CLSORB uses singular value decomposition to invert the horizontal and vertical corrector-to-BPM response matrices. The number of singular values used in calculating corrector values can be reduced to remove noisy patterns, or if any BPM or OCM is disabled. However, reducing the number of singular values can result in a final orbit that is not equal to the reference orbit defined by beam-based alignment.

A maximum corrector change corresponding to 0.05 microrads is included in the orbit correction algorithm. At each iteration the set of corrector changes is compared to this maximum and if any value is too large the entire set of corrector changes is normalized to the maximum. This prevents having a spurious beam position reading result in a largely disruptive correction being applied. This also allows the use of all the singular values in the correction.

Orbit corrections are applied approximately every 1.5 s, alternating between the horizontal and vertical planes. This rate is limited by the communication to the slow correctors.

The horizontal dispersion component is removed by making small adjustments to the RF frequency at every iteration.

BEAM POSTION MONITOR UPGRADES

Previously, Bergoz modules sampled the signals from the button monitors at a rate of 10 kHz and translated them to X and Y analogue positions at 2.5 kHz. This signal was digitized by one of four VME modules at 20 kHz. 254 samples were averaged and passed to the EPICS interface for distribution every half second. The Linux-based system [3] collected data acquired by each VME module in a sequential manner. The first module was polled until it was determined that the buffer was half full. Acquisition was then terminated for that module, its data extracted and these steps repeated for the other three modules in sequence (figure 2). This algorithm had an estimated dead time of nearly 90%. As the quality of beam position data drives the effectiveness of the entire orbit control system, increasing demands on orbit stability required this algorithm be replaced.

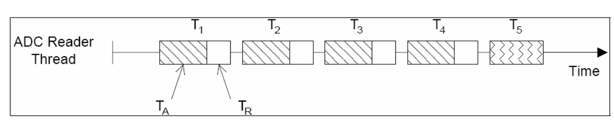

Figure 2: Timeline of data acquisition of Linux system. $T_1=T_2=T_3=T_4$ and $T_1=T_A+T_R$ where T_A is the duration spent acquiring by a single ADC and T_R is the readout time of that module.

The Linux system was replaced by the real-time operating system, RTEMS, and the digitization rate was reduced to 10 kHz. Unlike the polling-based design of the older system, the new version is interrupt-driven. Data acquisition on all BPM modules is initiated simultaneously, waits until half full interrupts have been received from all ADC modules, then transfers the data for processing. Now each ½-second update contains the average of 5120 samples (10 times 512 samples per half full buffer) taken simultaneously over the quadrants (figure 3). This corresponds to a reduction of noise in the BPM data by a factor of 4.4. The estimated dead time of the RTEMS system is only 5%.

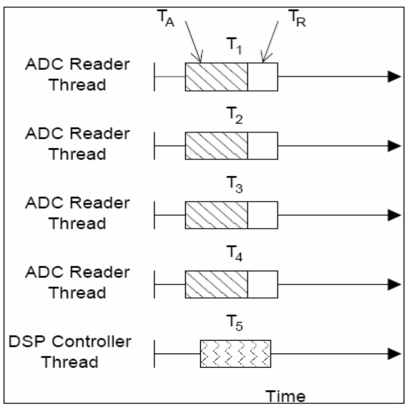

Figure 3: Timeline of data acquisition of RTEMS system.

To increase the rate of acquisition, a single half buffer of data can be used (512 samples) to have new data at 20 Hz. For faster rates, time-based interrupts are used rather than the buffer ½-full interrupt. The time scale can be adjusted to match rates required by the demands of a fast orbit correction algorithm.

FAST ORBIT CORRECTION

The goal is to create a flexible orbit control program running on RTEMS with Matlab providing the user interface and orbit display [4]. The new program can be used in one of two modes. One mode (assisted) mimics the original system and is useful for setup and troubleshooting and manually applying single correction steps. It is in this mode that the response matrix is calculated, orbit bumps are created, BPMs or OCMs are disabled and the number of singular values, fraction of overall correction and maximum corrector step size are defined. When the operator switches to the other mode (autonomous) all the necessary data is passed to EPICS/RTEMS where the acquisition, calculation and readout is performed.

Testing of the RTEMS orbit control has been done with the VME-connected subset of corrector magnets at 20 Hz with the interrupt-driven BPM acquisition and at 62 Hz with time-driven BPM acquisition. The general algorithm is to wait for BPM data update, calculate the difference in BPM position from the reference orbit and multiply the difference orbits to the respective horizontal and vertical BPM-to-OCM response matrices to get the corrector changes. These changes are compared to the maximum allowed step and scaled if needed. This data is then distributed to each power supply and an update signal sent to all horizontal and vertical correctors simultaneously. It is intended to extend this algorithm to use the fully coupled response matrix and calculate the corrections in both planes simultaneously while including the x-to-y and y-to-x coupling terms.

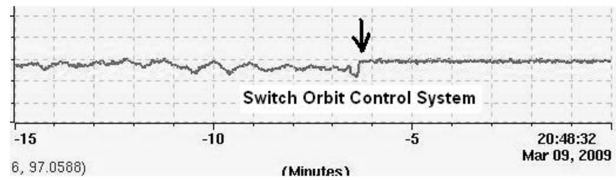

Figure 4: Sample horizontal BPM noise with Linux orbit control (left) and with RTEMS orbit control (right). One division is 5 microns.

Testing showed a decrease in orbit noise from 2-3 microns to under 1 micron with the machine in a static state for both 20 Hz (figure 4) and 62 Hz correction. For the tests, all singular values and a maximum corrector step of 2 microrads was defined. As a demonstration, one superconducting wiggler was ramped from off to full field in each of the three correction modes (figure 5). Due to orbit movement of over 100 microns during the ramp with the old orbit control, wiggler field changes were limited to beam injection periods. With the 20 Hz correction active the wiggler ramp created orbit shifts only up to 4 microns while at 62 Hz the wiggler ramp was nearly transparent.

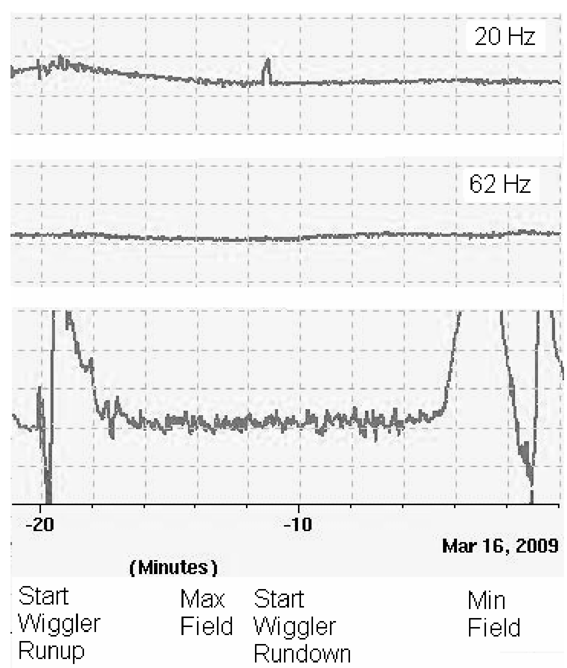

Figure 5: Comparison of orbits at a sample BPM during wiggler ramp in three modes, 20 Hz, 62 Hz and the Linux system. Vertical scale is 5 microns/division.

Prior to implementing this mode for user operations, the slow correctors will undergo an upgrade to fast communications. Studies with a high precision position sensitive detector will determine the final correction rate needed for optimum orbit stability. Both software and hardware provide the timing limitations, software being the read rate of the BPMs and the distribution of the corrector setpoints, the hardware mainly being that the thicker laminations in the sextupole correctors may impose a limit of about 75 Hz.

Further work will include applying the dispersion correction through Matlab at ~ 1 Hz. Other work will investigate current dependence in the BPM outputs. Current dependent offsets for each BPM have been measured by tracking the drifts in corrector setpoints over a typical fill/decay. A correction factor as calculated from a polynomial fit as a function of stored current can be removed from the raw BPM data.

INSERTION DEVICE COMPENSATION

Each of the permanent magnet insertion devices (IDs) has a set of correction coils that uses feed-forward tables to compensate for remnant 1st (I) and 2nd (II) integrals and in the case of Elliptically Polarizing Undulators (EPUs), quadrupole fields that remain following virtual shimming. [5].

The planar devices have copper wire mounted on the moving girders that the magnets are attached to. These are able to correct the Ix, Iz, and IIz fields up to 5 Gm and 1 Gm^2 respectively. The strength of the field changes with gap, but as the strongest corrections are needed at minimum gaps, the required current remains low. The procedure used to create the feed-forward tables is to move the ID gap to approximately 15 positions and cycle the current in each coil while recording the RMS orbit perturbation at all BPMs. A second order polynomial is fit to the RMS and the minimum defines the current needed at that gap. During normal operation of the ID a linear interpolation is used at a rate of 10 Hz to calculate the necessary power supply setting needed for all three coils.

The in-vacuum small gap undulator has 100 turns of Kapton coated wire arranged on the movable girders inside the vacuum vessel capable of creating up to 5 Gm Iz field at the minimum gap. Vertical correction is by two vertical corrector dipoles at either end of the device. A similar procedure to the planar undulators is used to create the feed-forward tables for this device.

A set of coils similar to the planar devices was originally designed for the first APPLE-II EPU. Following extensive virtual shimming and use of magnetic trim magnets a remaining strong skew quadrupole component necessitated the re-design of the correction coils. New coils were wound on aluminum frames (figure 6), covered with an acrylic conformal coat for further insulation and mounted to the stationary EPU support structure. Eight individual power supplies are used to power the coils to create the superimposed correction of Ix, IIx, Iz, IIz, and normal and skew quadrupoles.

The procedure for creating the feed-forward tables for the EPUs is complicated by the two modes of operations: circular polarization or linear/inclined polarization. For each mode, a complete set of 2-dimensional tables are measured as a function of gap and sub-girder position. The skew quadrupole correction is measured by monitoring the beam profile on the x-ray diagnostic beamline and adjusting the correction strength to keep the vertical beam size constant as the gap is varied. This correction mode is independent of polarization as the skew quad component is primarily gap dependent.

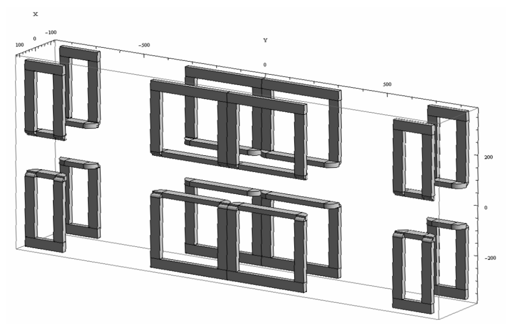

Figure 6: Schematic of new coil arrangement. The small coils are wired in series with adjacent large coils. This paired design was necessitated by space constraints.

In all above cases, the feed-forward tables are sufficient to keep the perturbations to the orbit under 1-3 microns during the normal operation of these devices. Implementation of the fast correction algorithm will further reduce the perturbations.

The consistency of the measured tables is investigated every run. The tables for the two planar devices have not been modified for a number of years. The in-vacuum device tables were tweaked slightly following the upgrade of the BPM signals and have not needed modification since. The EPU tables have required more frequent adjustments as small modifications were made to the physical coils to improve their performance and durability.

REFERENCES

[1] L. Dallin, R. Berg, J. Bergstrom, M. de Jong, X. Shen, R.M. Silzer and J. Vogt, "Canadian Light Source Status and Commissioning Results". EPAC2004, P. 2269.

[2] A. Terebilo. "Accelerator Toolbox for Matlab". SLAC-PUB-8732, 2001.

[3] R. Berg, L. Dallin and J. Vogt. "Orbit Control for the Canadian Light Source". EPAC2004, P. 2272.

[4] D. Chabot. CLS Document 5.2.39.4-Rev.0. "SR1 Orbit Control Design Note". 2008.

[5] E.g. M. Sigrist. CLS Document 17.18.25.1-Rev.0. "Assembly and Installation Summary of SM-EPU for ID10-1". 2006.