Workshop on Performance Optimization of Synchrotron Radiation Storage Rings

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The purpose of this workshop was to provide a forum, with user participation, for accelerator physicists working in the synchrotron light source field to discuss current and planned state-of-the-art techniques to optimize storage ring performance. The scope of the workshop focused on two areas: lattice characterization and measurement, and fundamental limitations on low frequency beam stability.

INTRODUCTION

Significant progress in the experimental determination and correction of Twiss parameters, dispersion, coupling, and position monitor and magnet offsets has been made in recent years. Recent results at NSLS, APS, and SSRL were the subjects of invited talks.

As understanding and correction of coupling continues to improve, micron- and even submicron-scale vertical beam sizes are being discussed, with corresponding increases in photon source brightness. With beam position stability specifications generally quoted in terms of a fraction of beam size, typically 5 to 10%, ultra-stable feedback systems are required to make use of the resulting high brightness.

The fundamental limitations in this area are electrical signal processing stability, sensor mechanical stability, and mitigation of noise sources. Separate invited talks from NSLS, SSRL APS-ASD, and APS-XFD dealt with the subtleties of these topics.

EXPERIMENTAL DETERMINATION OF OPTICS

In order to maximize the brightness and provide sufficient dynamic aperture in synchrotron radiation storage rings, one must understand and control the linear optics. Control of the horizontal beta function and dispersion is important for minimizing the horizontal beam size. Control of the skew gradient distribution is important for minimizing the vertical size. In a paper presented by J. Safranek, various methods for experimentally determining the optics in the X-ray ring at NSLS and at other laboratories was presented. The NSLS technique is novel in that an orbit response matrix containing thousands of measurements was used to determine hundreds of variables such as quadrupole gradient and roll errors, beam position monitor (BPM) gain and rotation errors, corrector magnet strength errors, in addition to linear lattice functions and dispersion. Agreement with theory is remarkable, with 4 x 10^-4 relative rms magnet strength determination being typical.

BEAM-BASED DETERMINATION OF BEAM POSITION MONITOR OFFSETS

The power of the EPICS control system together with high-level data acquisition and analysis tools developed by M. Borland and other APS physicists was shown in a presentation of recent results on beam-based BPM offset determination. For each of a set of local bump settings, the closed orbit at 80 BPM stations was measured as a function of the strength of a quadrupole magnet located within the local bump. From the local bump amplitude corresponding to minimal effect of the quadrupole on the BPMs, the reading on the BPM nearest to the varied quad which corresponded to its magnetic center was found. This technique has been successful at determining BPM-quadrupole offsets to within 100 microns, with the promise of significant improvement once reproducibility effects are better understood.

PHASE SPACE TRACKING

The richness and complexity of accelerator phase space was impressively shown in an invited talk by P. Tran of UCLA, presently working at SPEAR/SSRL. Using a horizontal injection kicker and a pair of BPMs with data acquisition and associated analysis software, one could clearly see the horizontal tune and bunch trajectories crossing a sixth-order resonance as a consequence of the amplitude-dependent tune shift. The horizontal phase-advance between the two BPMs and the respective beta function amplitudes used in calculating the normalized coordinates were obtained by an iterative, self-consistent least-square-fit of the normalized coordinates to the expected circular form of a linear Poincare’ map. Accurate tune determination was done using the Numerical Analysis of Fundamental Frequency technique.

The phase space tracking method has thus far been used to measure amplitude-dependent frequency shifts resulting from octupoles which are used for beam stabilization purposes.

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Additionally, coupling studies will be carried out with the SSRL phase space monitor.

BEAM STABILIZATION TECHNIQUES

State-of-the-art progress in orbit stabilization at the NSLS X-ray ring was described by O. Singh.\(^7,8,9\) Four kinds of orbit-stabilizing feedback systems are in operation. An analog global closed-orbit feedback system is based on nulling out four harmonics of the beam motion near the tune. This feedback system employs only one third of available BPMs, and it corrects the orbit motion up to 100 Hz. Local analog feedbacks fix the electron beam position at the BPMs just upstream and downstream of the insertion devices.

Radio frequency feedback is used to remove the dispersion-like horizontal orbit variation. This correction is updated at a five-second rate. A digital feedback system is based on reducing the eigenvector orbits (up to 24 eigenvectors). This feedback system samples orbit motion at all 48 positions. When the analog and digital feedback were used together, the typical measured orbit motion was less than 8 microns over many hours. With these highly efficient orbit feedback systems, the beam stability at the NSLS X-ray ring is now limited by the mechanical stability of the BPMs. Studies monitoring vacuum chamber motion from synchrotron radiation heating are underway with the goal of compensating for the BPM motion.

A comprehensive history of the development of beam stabilization techniques at SPEAR was presented by J. Corbett of SSRL.\(^10\) This included optics changes to reduce sensitivity to mechanical vibrations, modeling efforts, correction algorithms, injector design, orbit feedback hardware and software, upgrades of main power supplies, and diagnostics improvements. This information was relevant to improvement efforts for any synchrotron light source.

Y. Chung gave an update on the large digital signal processor-based closed orbit feedback systems under construction at the APS.\(^11\) A sampling frequency of 4 kS/s has been chosen to allow orbit correction bandwidth of better than 100 Hz, both locally and globally. Interesting results on the determination and performance of the APS amplitude to phase conversion-style beam position monitor electronics were presented.\(^12\) A 100-nm rms noise level in a 1-Hz bandwidth with 1 mA stored beam current has been achieved.

MECHANICAL STABILITY OF ACCELERATOR COMPONENTS

Recent progress on identification and reduction of low frequency sources of beam motion, both mechanical and electrical, were reported by G. Decker, S. Kim, L. Emery, and D. Shu from the APS.\(^13,14,15\) A vibration damping technique in use which reduces the Q of girder mechanical resonances by an order of magnitude was described. The global character of ground motion, namely the variation of power spectral density as the inverse fourth power of frequency, was reported. The typical scale of the ground motion in the APS accelerator tunnel is on the order of tens of nanometers rms in the band from 4 to 50 Hz, during quiet periods. Transient phenomena can cause micron-scale ground motions, however. Specifications on magnet mechanical and power supply electrical noise were stated, both of them based on an allowed rms beam motion equal to 5% of the transverse beam dimensions. L. Emery described an impressive piece of detective work which was used to track down a source of horizontal beam motion amounting to about 30 microns rms at 6.5 Hz. He showed a color spectrogram plot containing 360 BPM FFTs up to 30 Hz. One could clearly see the envelope of the 6.5-Hz peak vary with BPM index around the ring, consistent with beta function modulation, and correlated with a family of sextupole power supplies which had a 6.5-Hz current ripple. A scheme for comprehensive characterization of X-ray photon beam position monitors for use in offset compensation algorithms was described by D. Shu, together with some of the thermal and vibration design features of the monitors in use in APS front ends.

CONCLUSIONS

The SRI’95 workshop on performance optimization of synchrotron radiation storage rings facilitated an effective transfer of information between the labs on state-of-the-art techniques now in use and under development. Summarized in the references below is the essential content of the contributions from those attending the workshop. Work is well underway for providing micron-scale beam stability in synchrotron light sources, even including long-term thermal and mechanical drifts.

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REFERENCES


M. Borland et al., "Doing Accelerator Physics Using SDDS, UNIX, and EPICS," ICALEPCS'95 Proceedings (to be published) IEEE-NPSS.


J. Corbett, "Beam Stabilization at SPEAR," these proceedings.

Y. Chung et al., "Digital Closed Orbit Feedback System for the Advanced Photon Source Storage Ring," these proceedings.


S. Kim et al., "Investigation of Low-frequency Beam Motion at the APS," these proceedings.


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