Reduction of Open-Loop Low Frequency Beam Motion at the APS*

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Abstract

The Advanced Photon Source (APS) 7-GeV positron storage ring at Argonne National Laboratory (ANL) produces high brilliance bending magnet and insertion device x-rays for up to 70 x-ray beamlines. To efficiently make use of the storage ring's high brilliance, an extremely tight tolerance has been placed on positron beam stability, namely that the beam be stable to a level which is less than 5% of its rms size. This requirement amounts to ± 4.4 microns rms in the vertical plane and ± 17 microns horizontally, assuming 10% coupling. While real-time closed orbit feedback (discussed elsewhere in these proceedings) will be employed to exceed the required stability requirement, efforts are underway to identify and reduce sources of beam motion in the absence of feedback. These sources include ground- and water-system-induced vibrations in addition to power supply jitter and drift. Results to date of this effort will be presented.

I. INTRODUCTION

The low frequency beam stability requirements at the APS are very strict, namely that rms positron beam motion at the insertion device straight sections (β_x = 14.2 meters, β_y = 10.0 meters) be less than 4.4 microns vertically and 17 microns horizontally in a bandwidth 1-50 Hz. Sources of beam motion in this band are magnet vibrations induced by ground motion and water flow, and power supply noise from the large number of corrector power supplies installed in the ring.

The APS magnets are arranged in 40 similar sectors, each including five different girder designs. Three quadrupoles in a defocusing-focusing-defocusing (DFD) pattern, a sextupole, and two combined function vertical horizontal correctors are mounted on the first and fifth girder in each sector. Girder three holds four quadupoles in a DFFD arrangement, one sextupole, and two correctors. Girders two and four each support a dipole, two sextupoles, and a corrector. Each girder additionally supports an aluminum extruded vacuum chamber with a fixed tri-axial support near the center and two leaf-spring-type supports which allow thermal expansion during bakeout but which also constrain transverse chamber motion. The chambers are not mechanically coupled to the magnets except via their attachment to the girder. The particle beam height is nominally 1.4 meters above the floor.

Each girder is supported by three wedge jack supports mounted on two fixed pedestals grouted to the storage ring enclosure floor. Two jacks are near one end of the girder on one pedestal and at the other end is the pedestal with the single jack support. Shown in Fig. 1 is an end view of a girder 5. Visible are the pedestal, two wedge jacks, the box-frame girder, a six-pole combined function vertical-horizontal corrector magnet, and the storage ring vacuum chamber.

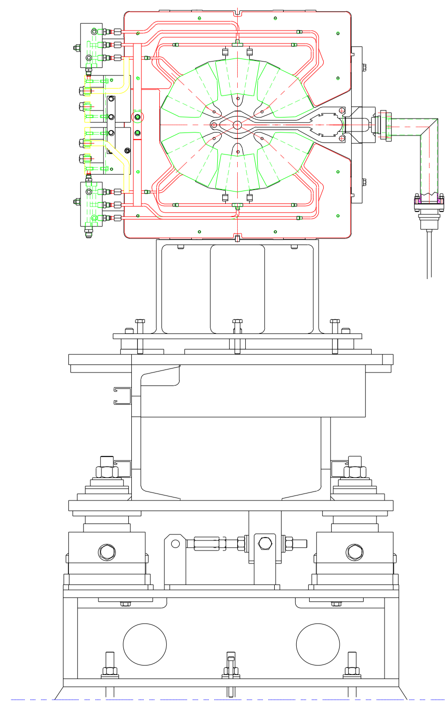

Figure 1: APS Storage Ring girder support structure

Considerable effort has been invested over the past several years toward understanding the ground motion environment at the APS and its impact on magnet motion, primarily regarding the strong focusing quadrupoles which have a large steering effect for even the smallest transverse motion. For this reason, the odd-numbered girders have been studied most extensively, as they support all of the quads.

Lattice modeling [1] indicates that random uncorrelated quadrupole motions of rms amplitude Δx_q result in rms beam motion of amplitude $17.3 \sqrt{\beta_x}\, \Delta x_q$. Since β_x = 14.2 at the insertion device source points, this amounts to a relatively large amplification factor of 65, a consequence of the strong-focusing low-emittance lattice. Fortunately, because each girder supports a quad triplet (the central two quads on girder 3 are both horizontally focusing), the situation is not quite so severe, since the dominant girder vibration mode involves correlated motion for all magnets on a girder [2]. For random uncorrelated rms transverse girder motion Δx_g, where all quads on the same girder move together, the beam motion is given by $\Delta x_b = 5.2 \sqrt{\beta_x}\, \Delta x_g$, yielding an amplification factor at the insertion device source point of 19.6.

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II. GIRDER VIBRATION

An outside contractor was brought in to measure and analyze ambient and driven girder vibration modes when the first production girders became available. Several girder assemblies were installed in the storage ring enclosure and instrumented with as many as 50 vibration transducers each over the course of a few weeks.

While many vibrational modes were discovered during the course of these measurements, the bottom line was that the quad girders are dominated by their lowest frequency mode at approximately 12 Hz for girders 1 and 5 and 10.5 Hz for girder 3. This mode is a horizontal bending mode, involving the quadrupoles essentially pivoting about the wedge jack supports as viewed in Fig. 1. The Q of these modes was approximately 100. Motion of the quad nearest to the single jack end is larger than at the double jack end of the girder by 50 to 100%. This induces a girder yaw component which was modelled and found to be a factor of 5 less important than the common mode transverse quadrupole motion [1].

Vertical magnet motion is much smaller in comparison to horizontal, the main mode of significance being a 45-Hz “bounce” mode where the end quads are stationary and the center quad(s) move vertically. While this mode shape is damaging given the FDF field pattern, the amplitude is very small and ground motion excitation in this band is also small.

These early studies were performed prior to the introduction of cooling water in the tunnel enclosure, and the ambient motion was exclusively driven by ground motion. Depending on the amount of activity taking place in the tunnel and on the adjacent experiment hall floor, rms ground motion in the tunnel varies from below 5 nm 4-50 Hz in the dead of night to as high as 100 nm during high activity days. This translated into horizontal quad motions as high as 0.5 microns 4-50 Hz which result in exceeding the beam stability specification. The specification for quadrupole motion is that the rms quadrupole motion be less than 113 nm in the band 4-50 Hz. This specification should keep beam motion to less than 19.6 x 113 nm = 2.2 microns, which conservatively meets the beam stability requirements even in the presence of 100% vertical horizontal coupling. Frequencies below 4 Hz were not included in the specification since ground motion is largest here and feedback is expected to work most effectively at low frequency.

Many techniques for reducing the horizontal magnet motion were attempted, with the best overall solution being to introduce a “sandwich” of visco-elastic material between the wedge jack supports and the pedestals. This material is ubiquitous and commonly found on everyone’s desktop in the form of transparent adhesive tape. Assemblies of this material sandwiched between steel plates produce excellent damping of low-frequency vibration both under shear and in compression. The configuration chosen for the APS is a “double-decker” sandwich using three steel plates and two 0.006” thick layers of Anatrol 216 visco-elastic material. These vibration pad assemblies are easily installed below the wedge jack supports with minimal impact on girder alignment. The effect of these damping pads is to reduce the Q of the lowest horizontal mode by roughly a factor of 10, and the ground-motion-induced rms motion 4-50 Hz by a factor of about 5. Figures 2 and 3 show typical horizontal magnet motion spectra taken simultaneously at similar locations in adjacent sectors, one with (sector 28) and the other without (sector 27) damping pads installed. The data were collected under operating conditions with magnet coolant water flowing. Figure 2 integrated yields 217 nm rms 4-54 Hz, while Fig. 3 gives 118 nm.

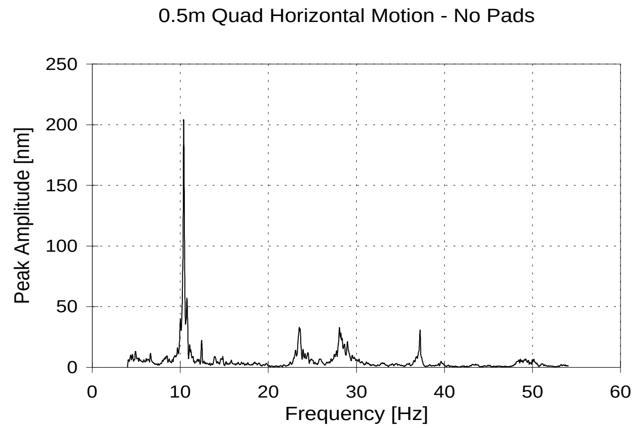

Figure 2: Quadrupole horizontal motion spectrum, no pads.

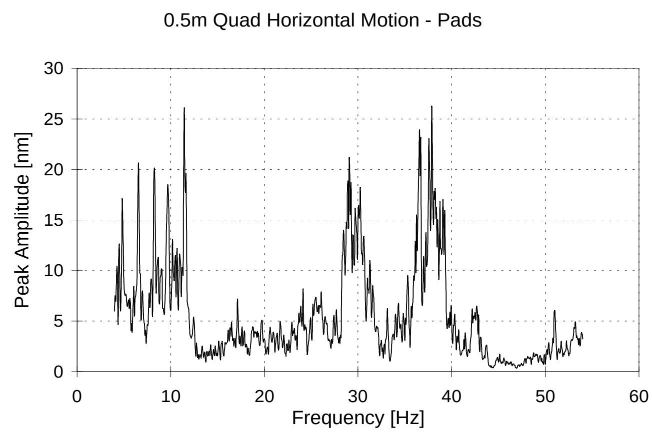

Figure 3: Quadrupole horizontal motion spectrum, with pads.

The integrated motion shown in Fig. 3 with water flowing, damping pads installed, and using the as-built water distribution system, was found to decrease from 117 nm rms to 42 nm rms when the water flow was stopped. This reduction occured primarily in the 6- to 12-Hz bands and at the broad structures seen near 30 and 38 Hz, respectively.

III. WATER-FLOW-INDUCED VIBRATION

Water distribution in the storage ring tunnel enclosure is accomplished via headers mounted to the ceiling and attached to magnets, synchrotron radiation absorbers, and vacuum chambers via both flexible and rigid connections. This is a large source of vibration excitation for the girders, as shown in Fig. 4, which indicates the effects of turning pumps off and back on in two adjacent storage ring sectors, one with vibration damping pads (sector 10), the other without (sector 11). The legend “S10 0.5 m X” conveys that this data is for a 0.5-meterlong quad in sector 10 in the horizontal plane and similarly for sector 11. Note that the sector without pads shows a strong response to water flow.

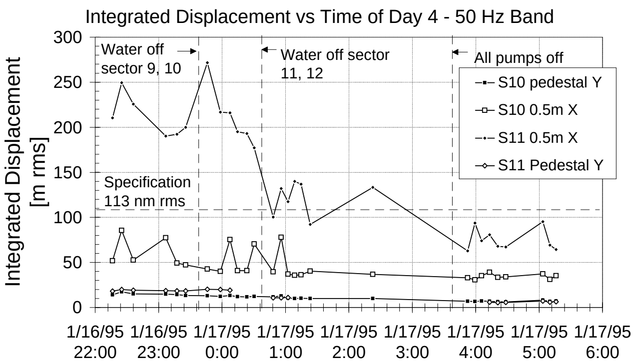

Figure 4: Effect of water flow on rms magnet motion

A major difference between this data and that of Figs. 2 and 3 is that, in addition to the inclusion of damping pads in sector 10, the overhead water distribution headers were reinforced by using closely spaced tabs welded to the pipe which were in turn bolted to the ceiling at approximately 3-foot intervals. This had the effect of reducing the pipe vibration from 12 microns rms 4-50 Hz to 3 microns. The spectrum of pipe motion before reinforcement was dominated by a broad resonance structure, centered in the 6- to 12-Hz band which was found to exacerbate the girder resonances. This feature is virtually eliminated by header reinforcement.

IV. STEERING CORRECTOR NOISE STUDIES

First turn trajectory and closed orbit correction is accomplished in the APS storage ring using 317 corrector power supplies [3] in each plane powering the 317 combined function vertical/horizontal corrector magnets [4]. These correctors are required to be relatively strong, ±150 Amps corresponding to more than ±1 mrad of steering to overcome eddy currents in the aluminum vacuum chamber for AC operation, while at the same time maintaining very low noise so as not to stir up the beam. The very large number of supplies makes this noise requirement even more restrictive since the beam motion noise contributed to by a single supply gets increased by a factor $\sqrt{317}$, assuming that the 317 correctors each make random contributions to beam jitter.

The specification for APS corrector power supplies is that the rms noise current in the band 1-10Hz be less than 0.6 mA. If all correctors operate at this specification and are uncorrelated, resulting beam motion will be less than 1 micron rms in the same band. Additionally, 40 of the correctors have thin-walled Inconel spool pieces in their bore and are to be used for wide-band (up to 100 Hz) orbit feedback. These correctors must generate a low amount of noise in a wider bandwidth. Noise studies on these wide-band correctors is underway.

Early measurements on a few correctors in their final configuration have been performed and indicate that over a large fraction of their dynamic range, the noise specification is met. The spectrum is generally flat in the 1-10 Hz band of interest, i.e. the noise power per unit frequency (power spectral density, or PSD) is constant. Many variables involving the detailed construction of the supplies have been investigated, including changing the regulation from shunt feedback to transductor feedback and employing a linear control power supply in place of the present switching unit. Additionally, the effects of cross talk between power supplies housed in the same cabinet have been investigated. The measurement of electrical noise at these low levels is complicated by the hostile noise environment inside and near the convertor cabinets. In-tunnel measurements of both current and field have been performed, using current transducers and Hall probes. Operating conditions of some units have been found with power supply noise as large as 2.5 mA rms, i.e., 4 times specification. This would imply beam motion near 4 microns rms, which is not in violation of the beam stability specification; however, all sources cumulatively must allow the beam motion specification to be met. Work is continuing in this area.

V. CONCLUSION

Substantial progress has been made in the area of reducing magnet vibrations resulting from ground motion and water flow. A factor of at least ten reduction in the Q of the lowest girder vibrational mode has been achieved by using sandwiched visco-elastic material installed at the girder support pedestal/ jack interface. The vibration specification for girders appears to be achievable. Installation of vibration reduction pads will be complete this year, followed by the effort to reinforce the water header system. Corrector power supply noise-induced beam excitation is under investigation, and measurement techniques are in hand.

VI. REFERENCES

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