INVESTIGATION OF OPEN-LOOP BEAM MOTION AT LOW FREQUENCIES AT THE APS

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Abstract

Sources of transverse beam motion in the APS storage ring have been investigated for ground-motion- and water-system-induced vibrations of the magnet and vacuum systems, and for power supply ripple. The displacement of magnets in a bandwidth of 4-30 Hz have been reduced significantly by inserting viscoelastic damping pads between the girder supports and pedestals, and by welding the magnet cooling headers to the ceiling of the storage ring tunnel. Current ripple on magnet power supplies was identified as a source of horizontal beam motion. Beam motion was measured without the closed-orbit feedback system activated. At β_x=15.4 m and β_y=10.4 m the rms beam motion in the 0.02-30 Hz band was 22.7 μm and 6.3 μm in the horizontal and vertical planes, respectively. A few narrow-band structures of the horizontal beam motion spectrum in the 1-4 Hz band have to be investigated further to identify the sources.

1 INTRODUCTION

The tolerances of the rms beam motion in the storage ring (SR) of the Advanced Photon Source (APS) [1] are to be less than 4.4 μm and 17 μm in the vertical and horizontal planes, respectively, in a bandwidth of 4-50Hz.

In the horizontal or vertical planes, the transverse beam motions or time-dependent closed-orbit distortions at position s in the SR due to a kick $\Delta\theta(s_k,t)$ at position s_k may be expressed as [2]

$$\Delta x_c(s,t) = \frac{\sqrt{\beta(s)}}{2\sin\pi\upsilon}\sum_k \Delta\theta(s_k,t)\sqrt{\beta(s_k)} \cdot \cos[|\psi(s)-\psi(s_k)|-\pi\upsilon], \tag{1}$$

where $\beta(s)$ and $\beta(s_k)$ are the beta functions at s and s_k, respectively, ψ is the betatron phase, υ is the betatron tune of the SR. The kick at s_k may be expressed in general as a Fourier series:

$$\Delta\theta(s_k,t) = \sum_j \frac{(\Delta Bl)_{kj}}{B\rho}\cos(\omega_{kj}t+\theta_{kj}). \tag{2}$$

Here $B\rho$ = 23.349 T·m is the beam rigidity corresponding to 7.000 GeV, and ω_{kj} is the angular frequency of the j-th kick at s_k.

When the transverse beam motions are superimposed to the beam offset for a single bunch of a beam in the SR, the beam signal to an rf beam position monitor (BPM) located at s is

$$f(s,t) = \sum_{n=-\infty}^{\infty}\delta\left(t-n\frac{2\pi}{\omega_r}\right)[\Delta x(s)+\Delta x_c(s,t)], \tag{3}$$

where ω_r is the angular revolution frequency, $\Delta x(s)$ is the offset of the transverse beam position, and $\Delta x_c(s,t)$ is the time-dependent transverse beam motion of Eq. (1). The frequency spectrum of Eq. (3) is as follows:

$$F(s,\omega) = \omega_r\sum_{n=-\infty}^{\infty}\left\{\Delta x(s)\delta(\omega-n\omega_r)+\frac{1}{2}\sum_{kj}|\Delta x_c(s,\omega_{kj})| [\delta(\omega-n\omega_r-\omega_{kj})+\delta(\omega-n\omega_r+\omega_{kj})]\right\}, \tag{4}$$

with $|\Delta x_c(s,\omega_{kj})|$ as the spectral amplitude of the beam motion, which will be shown as a sideband to the offsets of the beam position. Major sources of time-dependent kicks in the SR are the effective dipole field due to the displacement of quadrupole magnets (quads), power supply current ripple, induced field due to eddy currents in the vacuum chamber, and mechanical vibrations.

Displacement of the quads for the strong-focusing lattice of the SR causes a relatively high amplification factor of the beam motion. Random uncorrelated quad motions of rms displacement Δx_q result in rms beam motion of amplitude $17.2\beta^{1/2}\Delta x_q$, and the amplification for random girder motion is $7.4\beta^{1/2}\Delta x_{girder}$, where β at the insertion device source point is 14.2 m [3].

2 MECHANICAL VIBRATIONS

The vibration modes of the quad girders are dominated by a horizontal bending mode with lowest resonance frequency of approximately 10-11 Hz. The quad motion had a peak displacement of 210 nm at 10.2 Hz and an integrated rms displacement of 320 nm in 4-54 Hz.

In order to reduce the quad displacement, vibration damping pads were inserted between the wedged jack supports and the pedestals [3]. The damping pads are made of two layers of 0.15-mm-thick Anatrol-217 visco-elastic material and three layers of 1.6-mm-thick stainless steel plates. The damping pads were easily inserted below the jack supports with minimal impact on the girder alignment. The damping pads reduced the peak displacement by a factor of three and the resonance frequency was shifted downward a few Hz in general. The total rms displacement was reduced by a factor of two. After three successive simulated alignments to shear the pads up to 0.75 mm, no appreciable changes in Q-value at the resonance

0-7803-4376-X/98/$10.00

frequency have been observed. Besides the ground-motion-induced displacements, the cooling-water headers induced magnet displacements. Figure 1 shows measurements of the rms displacements for sector 10 after welding the water header to the ceiling of the SR tunnel and an unwelded sector 9. The vertical axis in Fig. 1 denotes horizontal rms displacement calculated for the 4-50 Hz band. Along the horizontal axis the measurement times are shown at the bottom, and the on/off status of the cooling water for the magnet and vacuum chamber are shown on the top. The data indicate that the impact of the vacuum chamber cooling water on the girder vibration is minimal. The magnet cooling water, on the other hand, increases the quad vibration by more than a factor of two, regardless of whether the headers were welded or not. The welds reduced the quad rms displacement from about 130 nm to 90 nm. The ratios of the displacements between the quads and pedestals, however, are not significantly different for the welded and unwelded headers.

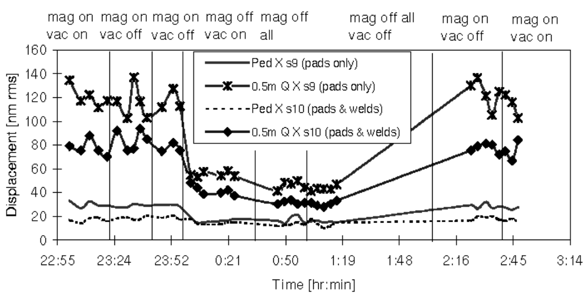

Figure 1: Displacements (rms in 4-50 Hz) of two quads and two pedestals with and without welding of the magnet cooling water headers. The on/off conditions of the cooling water for the magnets and vacuum chambers are shown on top.

To further investigate the impact of the welds when the cooling water was on, coherences of the vibrations between the quads and pedestals were measured; the data in the 6-11 Hz band are shown in Fig. 2(a). For the girder in the welded sector, the quad rms displacement was 44 nm compared to 106 nm for the one in the unwelded sector. At the same time the coherence for the unwelded case was lower, as shown in Fig. 2(b), which indicates that the water header contributed more than half of the vibration when the headers were not welded. The headers were welded as a test in two sectors; it was decided not to weld the whole ring due to cost vs. benefit.

3 MEASUREMENTS OF BEAM MOTION

Low-frequency beam motions in the SR were measured using a Hewlett Packard 89440A Vector Signal Analyzer [4] which obtains the frequency spectrum of the beam signal from rf BPMs [5]. The periodicity of the output signal from a BPM module is one-half the revolution frequency, $\omega_r/2$. This is due to the fact that beam positions are measured with a 180° phase shift on alternate turns for removal of systematic offsets. The amplitude of the signal

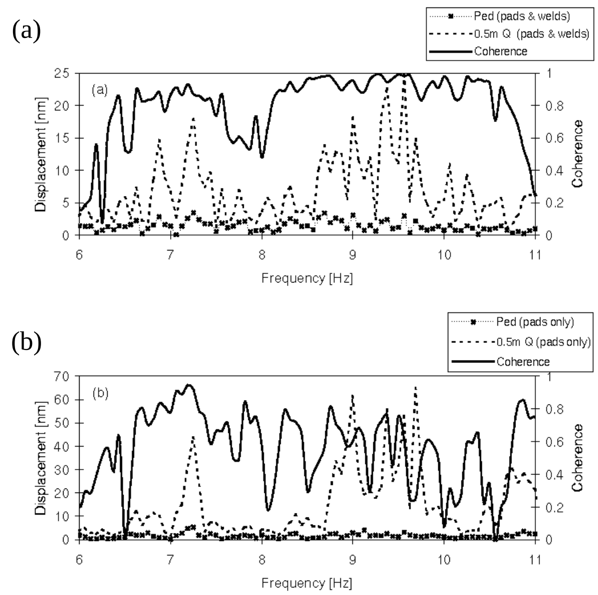

Figure 2: Coherence of the vibrations between the quads and pedestals (a) with and (b) without the welds. Without the welds the coherence is low, but the rms displacement in 6-11 Hz is 106 nm compared to 44 nm for the welded case.

at $\omega_r/2$ is the average position offset of the beam, $\Delta x(s)$ in Eq. (4), relative to the geometric center of the four buttons. Low-frequency beam motion corresponding to $|\Delta x_c(s,\omega_{kj})|$ produces an amplitude modulation of the position offset signal and appears as sideband to the $\omega_r/2$ “carrier.”

Figure 3 shows a typical horizontal and vertical beam motion spectra measured at a position of β_x=15.4 m and β_y=10.4 m in sector 12 in a bandwidth of ±30 Hz with a frequency resolution of 0.1 Hz. The magnitude of the beam offset signal at $\omega_r/2$=135.774 kHz (f = 0 in Fig. 3) is not shown in the figure. The horizontal rms beam motion in a bandwidth of 1-30 Hz was 33.1 µm with its major contribution in 1-4 Hz. For the vertical beam motion the rms value in the band 1-30 Hz was less than 5 µm. Only a few of the narrow-band structures in the spectra could be reproduced. When averaged from the measurements of 40 BPMs (one in each sector) at the same β_x and β_y, the rms beam motions were 22.7 µm and 6.3 mm in the horizontal and vertical directions, respectively.

In order to correlate the beam motion with that of a magnet, the beam motion was measured while a quad girder in sector 19 was being displaced with a “shaker.” The spectra of horizontal displacements for the AQ4 quad on the girder and the beam motion in an adjacent sector are shown in Fig. 4. The girder has a resonance frequency at approximately 10 Hz and the shaker has its own resonance frequency around 14 Hz. The amplification of beam/quad displacements is approximately two. This data and Fig. 3 indicate that horizontal beam motion due to a 1-µm quad displacement from a single girder vibration near 10 Hz would be difficult to detect.

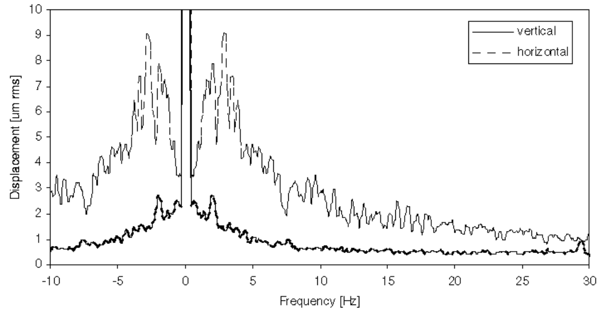

Figure 3: Horizontal and vertical beam motion spectra measured at a position of β_x=15.4 m and β_y=10.4 m with a frequency resolution of 0.1 Hz. The magnitude of the beam offset at 135.774 kHz (f=0 in the figure) is not shown.

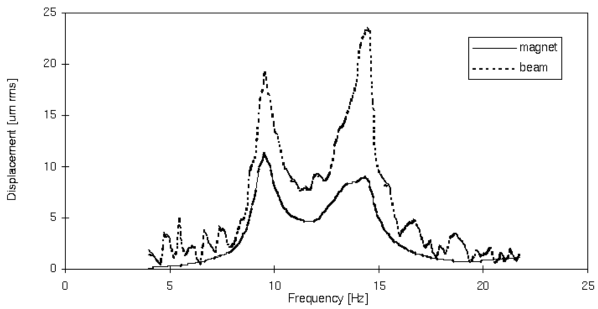

Figure 4: Correlation of a quad displacement in sector 19 and beam motion in sector 20 both in the horizontal direction. The quad girder was displaced using a shaker.

4 CURRENT RIPPLE

Statistics of current fluctuations for quads, sextupoles, and correctors were computed from 100 current samples, and some of those power supplies were measured in the frequency domain to identify the ripple spectrum responsible for the beam motion spectrum in certain bandwidths. A sextupole magnet power supply had current ripple of 0.2 A near 6.5 Hz. After modification of the power supply, the horizontal beam motion near that frequency was reduced from 21.9 μm to 8.5 μm [6]. The direct vertical field-integral for the magnet at the current ripple of 0.2 A should be less than 0.8×10^{-8} T·m within 1 mm of the magnetic axis. However, the ripple sextupole field due to the current ripple induces a considerable amount of eddy current in the aluminum vacuum chamber, which in turn induces a vertical field inside the chamber. The main contribution of the eddy current comes from the higher field at the larger aperture of the magnet. It should be noted that the direct and induced fields are out of phase. At the ripple current the induced field-integral was approximately 0.25×10^{-4} T·m, which is an expected field strength for a beam motion of 10-20 μm.

5 CONCLUSION

By inserting viscoelastic damping pads between the girder supports and pedestals, and by welding the magnet cooling headers to the ceiling of the storage ring tunnel, the displacements of magnets induced by the vibrations in the floor and water system were reduced by more than a factor of two. Current ripple of a sextupole magnet was identified as a source of beam motion. The average rms beam motion at β_x=15.4 m and β_y=10.4 m was 22.7 μm and 6.3 μm in the horizontal and vertical planes, respectively, in the band 0.02-30 Hz. Narrow-band structures of the horizontal beam motion spectrum, most of them not reproducible, have to be further investigated, the 1-4 Hz band in particular.

6 ACKNOWLEDGMENTS

The authors gratefully acknowledge J. Galayda for his encouragement and direction of the work and L. Emery for his helpful discussions on beam motion induced by current ripple. This work was supported by the U.S. Department of Energy, Office Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

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