Investigation of Passive Vibration Damping Methods for the Advanced Photon Source Storage Ring Girders

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Abstract

Beam stability is a major concern for the operation of the APS. One of the many contributing factors to electron-beam instability is mechanical vibration of the accelerator components especially the focusing magnets. The electron beam should be stable to 5% of its rms size to maintain the specified photon beam stability. The APS uses steel girders to support the conventional magnets and vacuum chambers in the storage ring (SR). Three pedestal and jack assemblies support the girders. Damping pads are presently installed between the pedestals and the jacks. These damping pads have been shown to be very effective in reducing the fundamental girder-vibration mode. The horizontal vibration levels of the SR quadrupole magnets are presently within specification at between two and four times the ground motion, i.e., 50-100 nm rms (4-50 Hz). Future improvements to the APS beam quality would require a further reduction in girder vibration. Several options for reducing the vibration of the girders and magnets are discussed, and the measurement results are presented.

Keywords: vibration damping, damping pads, viscoelastic, storage ring

1. Introduction

This study is a continuation of work that was done at the APS during the construction phase to reduce mechanical vibration of the storage ring quadrupole magnets [1,2,3]. The previous publications detailed the magnet and girder systems and the damping methods chosen for the APS SR girders. The damping system consists of a sandwich of stainless-steel plates and Anatrol 317 visoelastic material. These plates are placed between the girder jacks and the floor-mounted pedestals. Although these damping pads are clearly very effective in reducing the fundamental girder resonant motion, they do not dampen other vibration modes, such as the quadrupole magnet to girder motion. The quadrupole magnets are mounted to the girders with aluminum blocks with shims or jacks and without damping pads at the interface. The quadrupole magnets vibrate at a resonant frequency of approximately 24 Hz.

This study explores methods to reduce the magnet motion even further by using simple passive damping techniques between the magnets and girders. Studies were also performed to determine any benefits of using four-point girder support or alternate three-point support scheme.

2. Experimental Setup

2.1 Girder Configurations

Since time in the SR is very limited during maintenance periods, a spare girder/magnet assembly was used on the experimental floor to study several different damping configurations and girder support schemes. Figure 1 is an image of the girder used for this study.

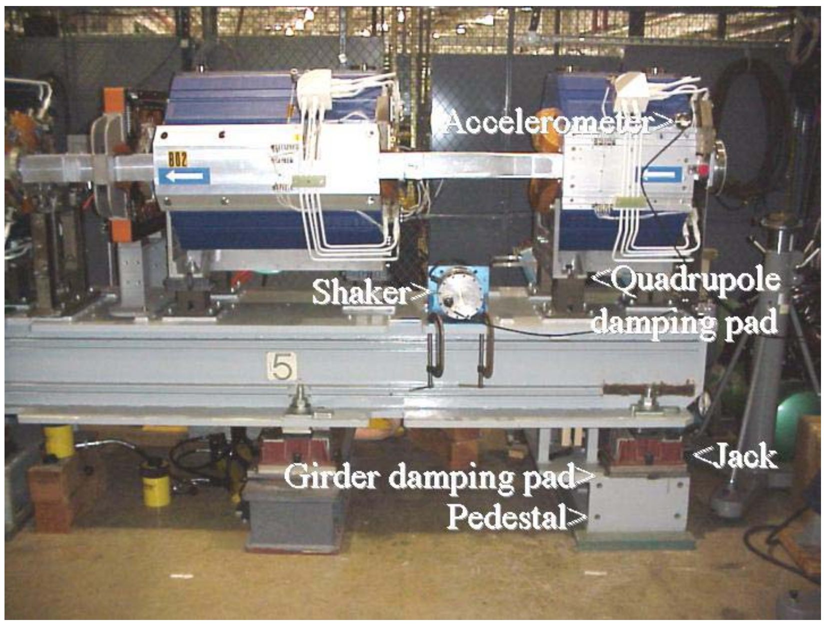

Fig. 1: SR girder number 5 showing the locations of the damping pads, shaker and quadrupole accelerometer.

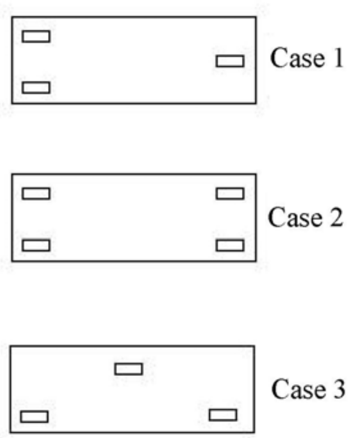

Fig. 2: The three girder support configurations showing the jack positions.

Three different methods of girder support were used. Case 1 is the configuration method used in the APS SR, with two jacks near one end of the girder and one jack centered at the opposite end. Figure 2 shows schematically the three configurations of jacks used for this study. Case 2 used four jacks, and Case 3 used three jacks with a wide stance.

Three damping configurations were used for each of the three girder support cases. The damping configurations were; undamped, girder-damped, and girder/quadrupole-damped. The girder-damped configuration used the standard SR damping pads (Fig. 3). The girder/quadrupole configuration used both the SR damping pads and quadrupole damping pads made with 3M-468 visoelastic material between two 3-mil stainless-steel shims.

Fig. 3: A SR standard damping pad and the smaller quadrupole damping pad used for this study. One-foot rule shows scale.

2.2 Measurement Methods and Data Acquisition Hardware

A Hewlett Packard 35670A dynamic signal analyzer (DSA) and two PCB 393B31 seismic accelerometers were used for the ground and quadrupole magnet vibration measurements. Two measurement methods were employed; one being a swept-sine the other being a fast Fourier transform (FFT).

The swept-sine measurements used an accelerometer mounted to the quadrupole magnet and a lower sensitivity accelerometer mounted to an inertial shaker, which was used to excite the girder motion. The source output from an HP35670A DSA was fed to a Kepco bipolar power supply to drive the shaker. The DSA was configured to automatically sweep the frequency from 5 to 30 Hz with 401 points per sweep. The source level was automatically controlled to keep the shaker acceleration relatively constant throughout the frequency band in order to maintain a constant energy at each frequency. The transfer function of the quadrupole accelerometer signal to the shaker accelerometer signal represents the gain of the magnet motion relative to the shaker motion. The transfer function H(f) is defined for this work as the average cross power spectrum of the magnet acceleration divided by the average cross power spectrum of the ground or shaker acceleration.

$$H(f) = \frac{\overline{G_m(f) \cdot G^*_m(f)}}{\overline{G_g(f) \cdot G^*_g(f)}}, \tag{1}$$

where $G_m(f)$ is the FFT of the quadrupole magnet acceleration, $G^*_m(f)$ is the complex conjugate, and $G_g(f)$ is the FFT of the ground acceleration.

The FFT measurement method used an accelerometer mounted to the quadrupole magnet and an accelerometer mounted to the downstream pedestal near the floor. The DSA was set up in the FFT mode with a frequency band of 5 to 30 Hz and frequency resolution of 0.0244 Hz. The transfer function of the magnet accelerometer signal to the pedestal accelerometer signal represents the gain of the magnet motion relative to the ambient ground motion.

3. Measurement Results

3.1 Swept-Sine Data

Figure 4 is a plot of three swept sine transfer functions with the Case 1 girder support configuration. The effectiveness of the girder damping pads in reducing the 9.5 Hz girder resonance and the quadrupole magnet damping pads in reducing the 24 Hz components can be seen in this plot.

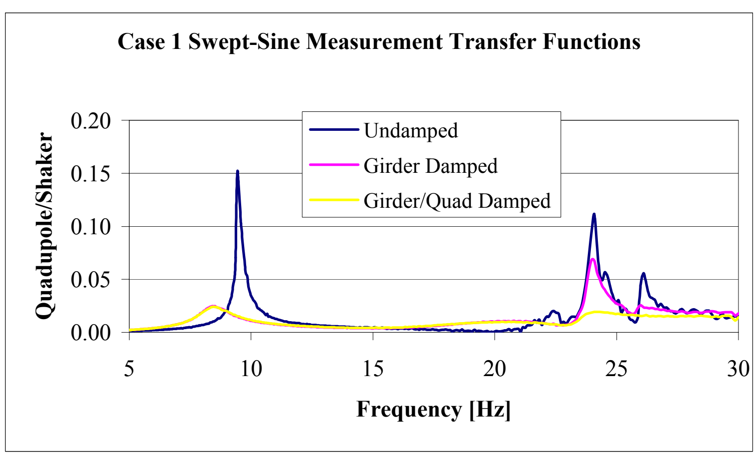

Fig. 4: Swept-sine transfer function spectra with the Case 1 girder support configuration, no damping, girder damping pads, and girder/quadrupole damping pads.

3.2 FFT Data

Figure 5 is a plot of the FFT results with the same damping configurations as in Figure 4. The transfer function is the quadrupole motion relative to the ground motion. The results are very similar to the swept-sine measurements. The effects of the quadrupole damping pads are evident in the data near 24 Hz.

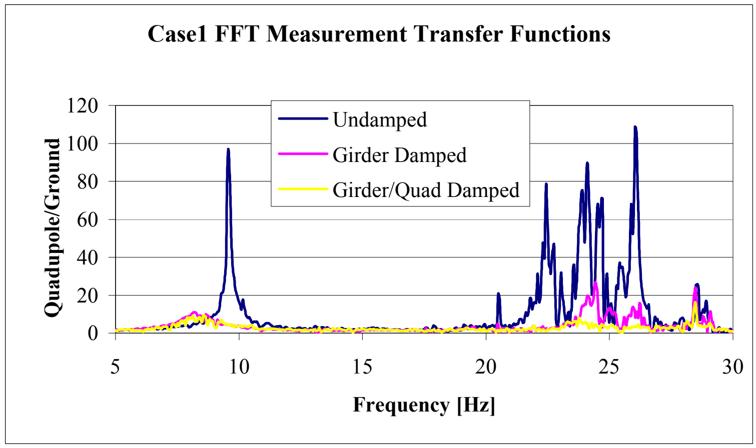

Fig. 5: FFT transfer function spectra with the same jack and damping configuration as in Figure 3. Note that the responses are similar to the swept-sine measurement results.

In order to compare the various girder support and damping configurations, the integrated band power for each transfer function was calculated. The band power for each transfer function was then normalized to the highest band power, which for the swept-sine method was the Case 3 undamped measurement. This procedure was done for both the swept-sine and the FFT measurement data. Figure 6 is a plot of the results of this normalization for the swept-sine measurements.

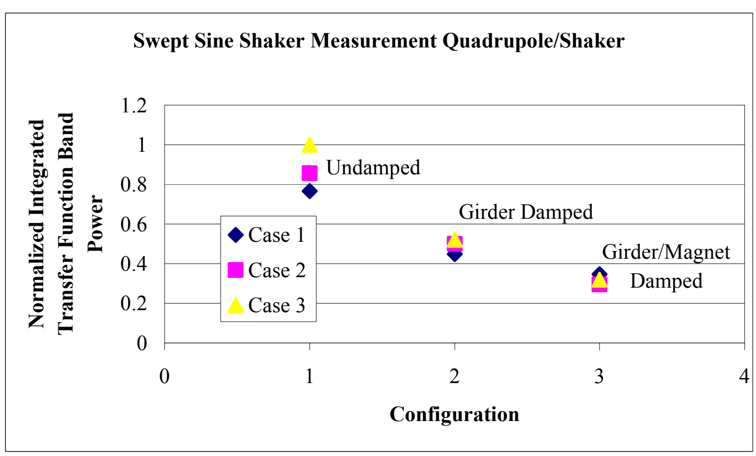

Fig. 6: The normalized integrated band powers of the swept-sine transfer functions for each damping and girder support configuration. A lower value indicates more effective damping and a lower overall gain in motion from 5 to 30 Hz.

The same procedure was done with the FFT data, and the results are plotted in Figure 7. The FFT band power values were normalized to the value for the Case 1 configuration. It is interesting to note that the Case 3 configuration had the largest gain for the swept-sine measurement, whereas the Case 1 configuration had the largest gain for the FFT measurement.

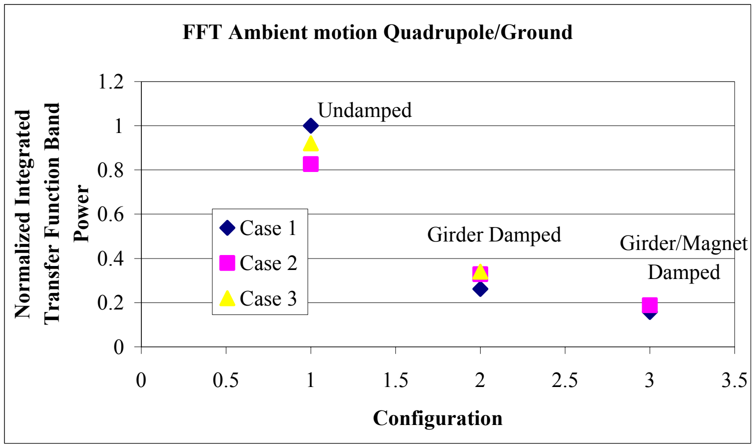

Fig. 7: The normalized integrated band powers of the FFT transfer functions for each damping and girder support configuration. A lower value indicates more effective damping and a lower overall gain in motion from 5 to 30 Hz.

4. Conclusions

The measurement results indicated small differences in the gain of the quadrupole magnet motion for the three girder support jack configurations. The Case 1 configuration had the lowest gain for the undamped and the girder-damped cases. Apparently no significant improvement would be realized by changing the girder support configuration.

The integrated vibration gain for the girder-damped case is 30% of the gain with no damping. The gain for the girder and quadrupole-damped case is 16% of the gain with no damping. The quadrupole damping pads are effective in reducing the 24 Hz components, which are due to the quadrupole-to-girder resonance. From these results it appears the overall vibration level could be reduced by a factor of two of the present value by installing damping pads between the quadrupole magnets and their supports. Further work is planned to study the effects quadrupole-magnet damping pads have on cooling-water-induced vibrations.

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6. References

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