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Performance of the Vibration Damping Pads in the APS Storage Ring

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Abstract

Beam stability goals for the APS storage ring require that its quadrupoles' vibrations be limited to 110 nm (rms, 4-50 Hz). Viscoelastic damping pads were installed under the girders in order to bring down the vibration levels to within the specified range. This paper presents the design of the damping pads and the results of recent vibration tests to evaluate their performance.

Keywords: Vibration Damping, Damping Pads, Viscoelastic, Storage Ring

1. Introduction

High brilliance of the third generation of light sources requires exceptional beam stability in the storage rings. Important factors that affect the beam stability have been identified as power supply jitters, electronic drifts, temperature fluctuations in the ring, and ground and flow-induced vibrations.

The particle beam in the APS storage ring is required to be stable to within 5% of its rms size [1]. Vibration induced beam motion is assigned 15% of the beam stability budget. This results in a vibration specification for the storage ring magnets, namely, rms horizontal displacement of the quadrupoles is to be less than 110 nm in 4-50 Hz frequency range. Vibration measurements on as-built girder-magnet assemblies showed that the measured motion exceeded this specification by a factor greater than 2. Viscoelastic damping pads were subsequently installed [2,3] to reduce the vibration levels.

Vibration tests are ongoing at the APS to monitor the performance of the installed damping pads, to study other damping schemes to further reduce the vibration levels, and to develop practical guidelines for designing girder supports with damping pads. The results of recent tests are discussed in this paper.

2. Viscoelastic Damping Pads for the APS Girders

The APS storage ring is 1104 m in circumference and consists of 200 girder-magnet assemblies arranged in 40 identical sectors. One of the girder-magnet assemblies with three quadrupoles, one sextupole and two corrector magnets, is shown in Fig. 1. The assembly weighing approximately 14,000 lb is supported on three wedge jacks used for height alignment. The jacks are placed on two steel pedestals grouted to the floor. Aluminum spacers or steel plates are used between the magnets and the girder, except for the middle quadrupole, which is mounted on smaller wedge jacks for height adjustment.

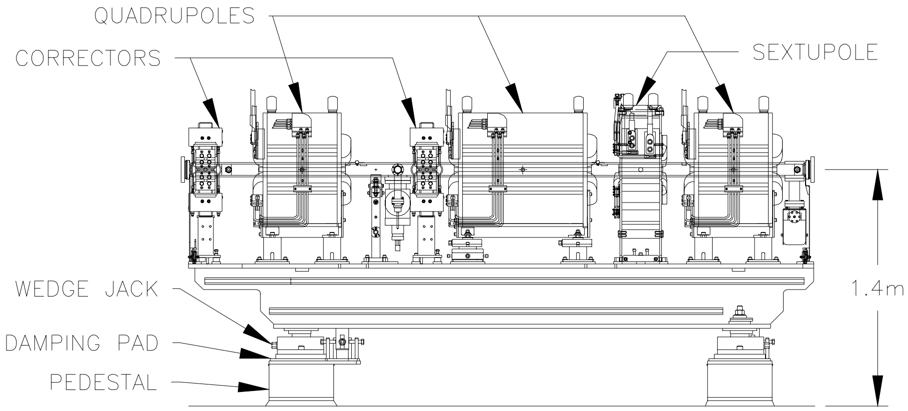

Fig.1: An APS girder-magnet assembly

The wedge jacks are the weak structural links of the girder-magnet assembly. With centers of mass of the magnets approximately 1 m away from the main jacks, the entire assemble is subjected to torsional vibrations (resembling an inverted pendulum) in the fundamental mode. Moving the alignment jacks as close to the magnets as possible can reduce vibration amplitudes; however, with magnet-girder assemblies already built, this option was impractical at the APS.

Extensive vibration measurements showed that the quadrupoles' rms displacements in 4-50 Hz band varied from 200 nm to 500 nm. The wide difference in values was due to construction activities at the site and flow-induced vibrations of water headers. The lower values were obtained during quiet nights with ground rms displacement of about 25 nm and with water-headers rigidly attached to the ceiling.

Following experimental evaluations of several damping methods, viscoelastic pads were selected to reduce the vibration levels. The pads, 12" x 8" in size, consist of three 1/16" stainless steel plates joined by pressure-sensitive adhesive films of proprietary acrylic materials. Relative motion between the stainless steel plates induces large cyclic shear strains in the films resulting in substantial energy dissipation. Anatrol 217 [4] damping material (in the form of 0.006" adhesive films) was selected for the APS damping pads for reasons of its performance, cost and availability.

The performance of the damping pads was evaluated during the initial installation in 1994, and subsequently during a maintenance shutdown in December 1999. Vibration studies in 1994 were conducted with and without the damping pads. In 1999 the tests were done only with the installed damping pads since the pads could not be removed within the APS operational constraints. For these three cases, the PSD (power spectral density) of horizontal displacement of a quadrupole magnet is plotted in Fig. 2. Without the damping pads under the wedge jacks, the peak value of PSD, measured in 1994, was 2.3×10^5 nm^2/Hz. It reduced by a factor of 10, to 2.3×10^4 nm^2/Hz, with the damping pads. The value with damping pads dropped further to 1.6 x10^3 nm^2/Hz in 1999. The corresponding rms displacements in 2-50 Hz range were 230 nm, 130 nm, and 53 nm.

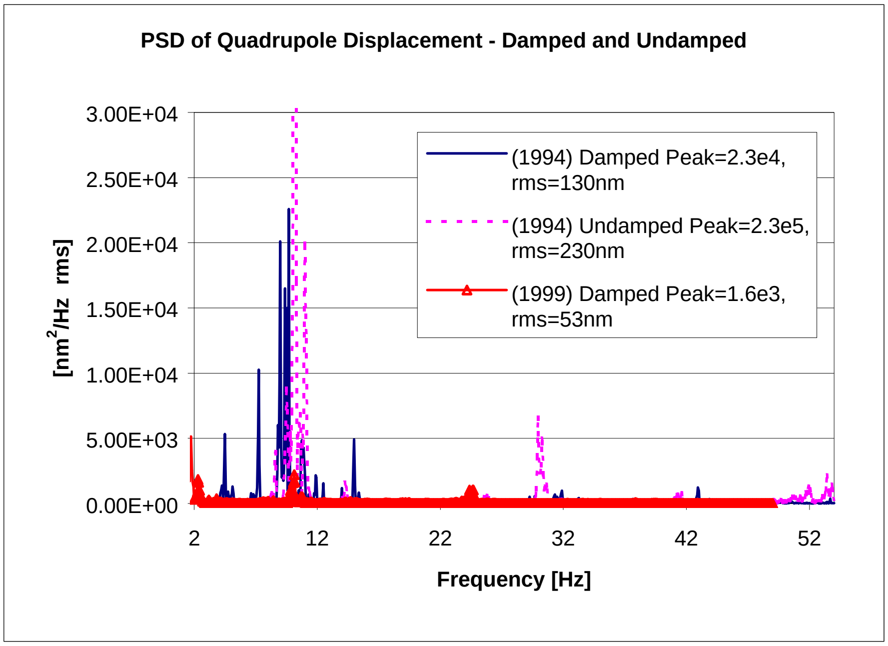

Fig. 2: Response of an APS quadrupole to ground motion

The ground motion in each case had an rms displacement of about 25 nm. However, because of higher pressures (approximately 180 psi) in the water headers, the flow-induced vibrations were considerably higher in 1994. By trimming the pump impellers, the pressures were brought down to about 115 psi, which led to lower header vibrations. This drop is yet to be quantified by measurements, but it was quite evident from the much reduced noise level in the storage ring. Nevertheless, the difference in the performances of the pads in 1994 and 1999 suggested further tests in simpler configurations.

3. Test Pedestals

Vibration studies were performed on three simple test pedestals (Fig. 3). Steel tubes of the 46.5” tall pedestals have outer diameters of 4”, 5”, and 6”, and wall thickness of 0.095”, 0.125” and 0.188”, respectively. Each pedestal has a welded base plate of 12” in diameter and ¾” in thickness. A support plate, 10” in diameter and ½” in thickness, is welded on the top.

Figure 3 also shows damping pads used in the tests. The base-damping pad consists of three stainless steel plates, 16”, 12” and 12” in diameter, and ¾”, 1/8” and ½” in thickness, respectively. The bottom (16”) plate is fixed to the floor by anchor bolts and

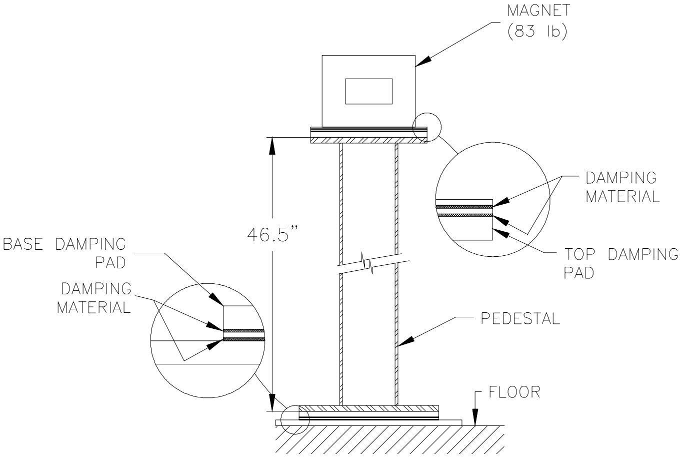

Fig. 3: A test pedestal with damping pads

the base of the pedestal is bolted to the top plate of the pad. The damping pad at the top also consists of three stainless steel plates of 10" diameter joined with Anatrol 217 films. This damping pad is installed by bolting its lower ½" thick plate to the top support plate of the pedestal. The magnet core weighing 83 lb is supported on the upper 1/8" thick plate.

4. Test Results

In the first test the magnet response was measured for the three pedestals without damping pads. The PSD plots (Fig. 4) for the displacements show peaks at

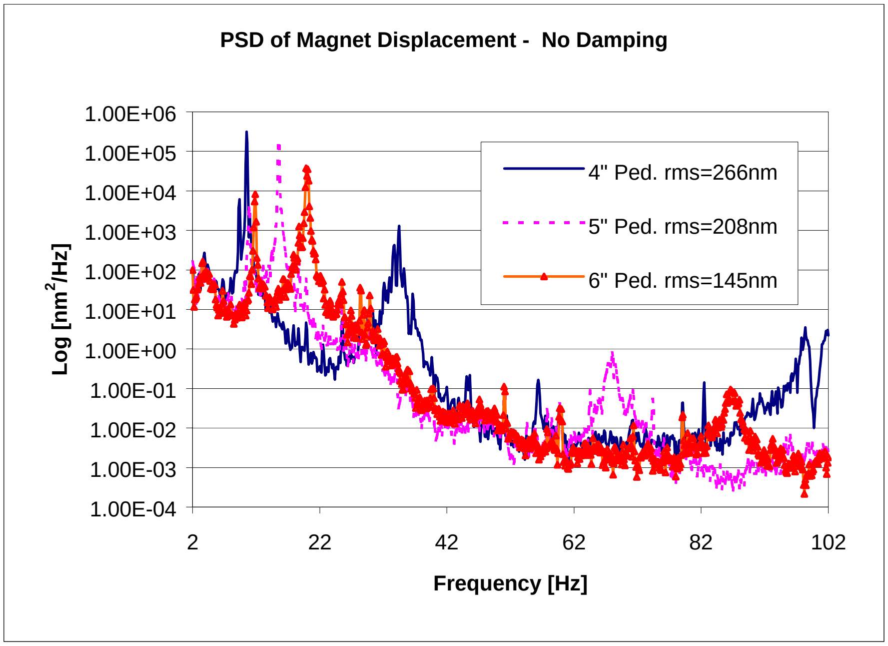

Fig. 4: Magnet response to the ground motion - undamped pedestals.

natural frequencies, 10.5, 15.6 and 20.3 (Hz), respectively, for the 4”, 5” and 6” pedestals. In 2-102 Hz band, the corresponding rms displacements are 266 nm, 208 nm, and 145 nm. The rms values for the ground displacement are 20 nm, 19 nm and 18 nm, respectively, yielding ground-to-magnet displacement magnifications of 13.3, 10.9 and 8.1. This shows that the displacement magnification is reduced significantly as the pedestal stiffness is increased. The reduction is mainly due to the sharp drop in ground excitation at higher frequencies (see Fig. 5). In comparison, under random base excitation the rms displacement of a one-degree of freedom system increases proportional to the square root of the resonant frequency [5].

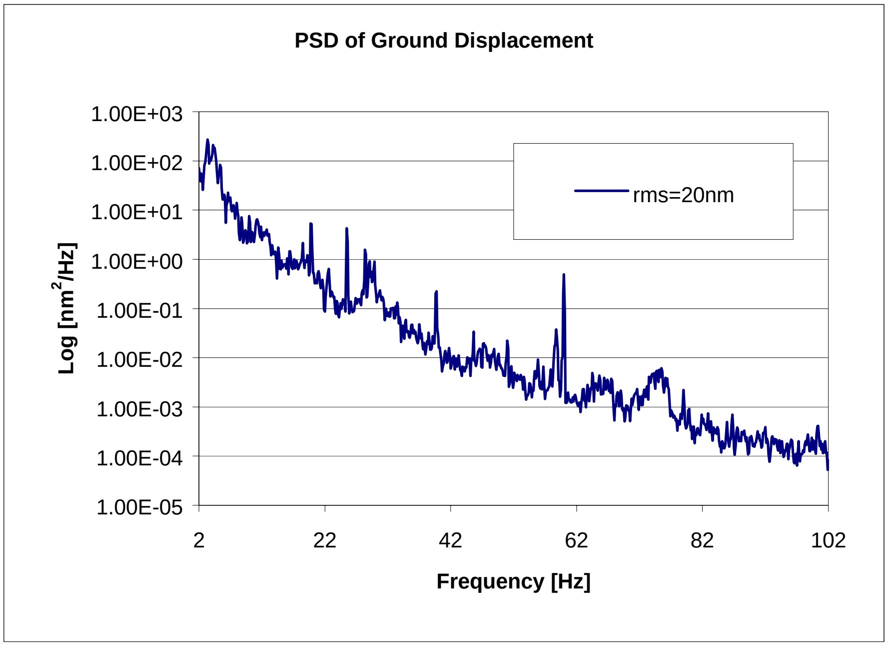

Fig. 5: A typical PSD of ground displacement at the APS site (1999).

Figure 6 shows the magnet response for the 4”, 5” and 6” pedestals with damping pads at the base only. The peaks at the damped natural frequencies are lower by two orders of magnitude and are considerably less sharp. Resulting rms magnet displacements are 52 nm, 37 nm and 36 nm for ground displacements of 21 nm, 18 nm and 18 nm, respectively. The ground-to-magnet displacement magnifications are 2.50, 2.05, and 2.00. These results show that: (1) damping pads under the pedestals can reduce the displacement magnification by a factor of 4-6, and (2) the magnet displacement reduces with increasing pedestal stiffness, but at a much lower rate than that without the damping pads.

The results with both the base and the top damping pads are plotted in Fig. 7. At lower frequencies the upper damping pad provides little additional damping. All steel plates of the damping pad tend to move together with the magnet core in this frequency range, and so no significant energy absorbing strains are induced in the viscoelastic films.

Such strains are induced at higher frequencies; however, the magnet motion at higher frequencies is much lower because of the sharp drop in the ground excitation. The rms displacements of the magnet on the three (4", 5" and 6") pedestals are 45 nm, 37 nm and 34 nm, respectively. The corresponding ground excitations are 21 nm, 18 nm and 17 nm. Displacement magnifications for this case are 2.14, 2.05 and 2.00, which are about the same as those obtained for the case when only the base-damping pad is used.

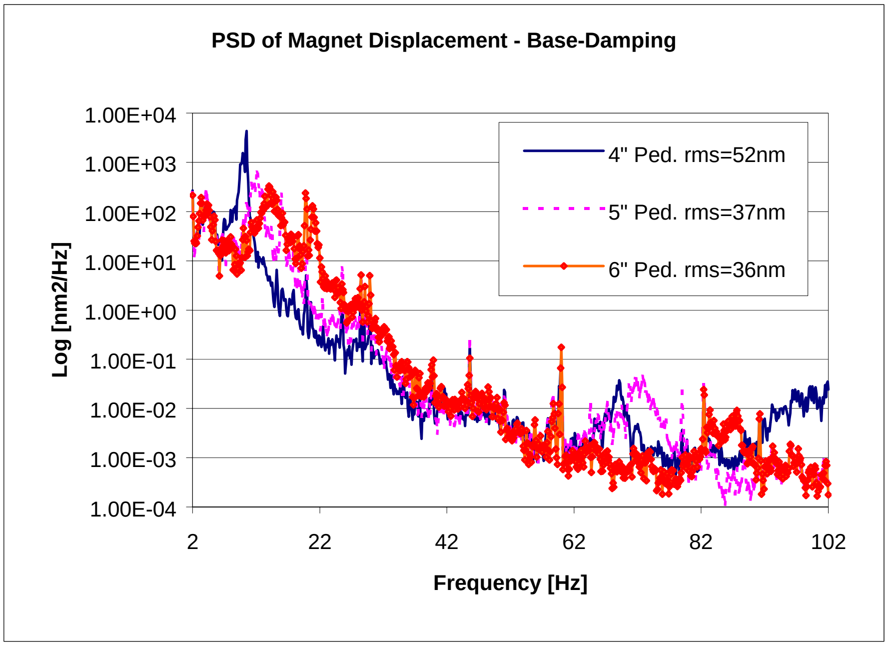

Fig. 5: Magnet response to the ground motion – pedestals with base damping.

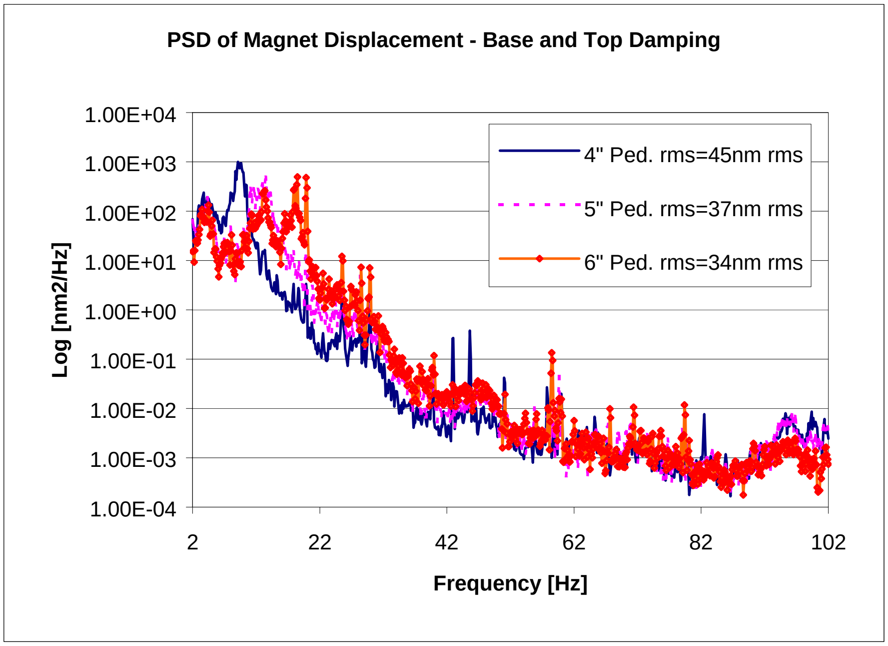

Fig. 6: Magnet response to the ground motion – pedestals with base and top damping.

5. Conclusions.

The following conclusions can be drawn from the vibration studies presented in this paper:

- Viscoelastic damping pads (such as those made with the Anatrol 217 adhesive films) can reduce the ground-to-magnet displacement (rms) magnification to about 2 - 3. The magnification can be considerably higher without the damping pads (approximately 10 for the cases presented) depending on the stiffness of the support system and the location of the alignment jacks. The peak displacements at natural frequencies can be reduced by more than one order of magnitude
- Stiffer supports (girders or pedestals) result in lower rms displacements because the ground excitation reduces sharply at higher frequencies. This effect is considerable less significant when the supports are damped at the base. Damping pads, therefore, provide a more cost-effective solution to reducing vibration levels than increasing the support stiffness.
- The damping pads should be installed closer to the ground in order to intercept the ground excitation before it is magnified by the weaker elements of the support system (e.g. alignment jacks). The alignment jacks should be located closer to the magnets.

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