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Passive Vibration Damping of the APS Machine Components

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ABSTRACT

The accelerator and beamline components of the APS have stringent vibration criteria in order to meet the beam stability requirements. For instance, the vibration amplitude of the storage ring quadrupoles is restricted to 0.11 μm (rms) over a frequency range of 4-50 Hz. Damping pads, consisting of thin viscoelastic films sandwiched between stainless steel plates, have been designed for passive vibration damping. Results presented in this paper show that the damping pads under the storage ring girder-magnet assemblies reduced the vibration amplification factor Q from over 100 to 8. The broad band rms motion of the magnets was reduced by a factor of 2.5 to 3. Preliminary results for a monochromator housing show a potential use of such damping pads for vibration control of beamline components. Radiation and creep effects on the damping pads' performance are considered.

I. INTRODUCTION

The Advanced Photon Source (APS) at Argonne National Laboratory is a synchrotron radiation facility designed to produce extremely brilliant x-ray beams for a broad range of scientific research. In this facility, a positron beam is accelerated to 7 GeV and injected into the ultra-high vacuum chamber of a 1104-m-circumference storage ring (SR). Approximately 1500 electromagnets are placed in 40 similar sectors of the SR to steer and focus the beam in a stable closed orbit. The magnets in each sector are arranged in a Green-Chasman lattice, supported on five steel girders numbered 1 to 5. A typical girder-magnet assembly with its support and alignment hardware is depicted in Figure 1. As shown, three quadrupoles, one sextupole, and two corrector magnets are mounted on a number 1 steel girder. The girder-magnet assembly, weighing approximately 14,000 lb, is supported on three alignment wedge jacks that are placed on top of two steel pedestals grouted to the floor.

An extremely tight tolerance has been placed on the positron beam motion to prevent the emittance growth that degrades the brilliance of x-ray beams. One significant source of beam motion is the submicron-range vibration of the SR quadrupole magnets. The magnet vibration is induced by both the floor vibration of the SR tunnel and the flow-induced vibration of the water headers. The specification for the acceptable SR quadrupole motion is an rms displacement of less than 0.11 μm in the 4-50 Hz frequency range[1]. Frequencies below 4 Hz are not included in this specification since the beam motion in this range can be corrected using the feedback system and corrector magnets. Above 50 Hz, the input excitation from the floor is usually insignificant and can be neglected.

Vibrations of the beamline components, such as mirrors and monochromators, also tend to degrade the x-ray beam's brilliance[2,3]. The damping pads discussed in this paper, although designed originally for the girder-magnet assemblies, can be easily implemented in the support designs for the beamline components. Moreover, the simple design of the pads also permits their use as retrofits for vibration damping in existing facilities.

II. VISCOELASTIC DAMPING MATERIALS

A large number of damping mechanisms and damping materials were investigated to bring the SR quadrupole vibrations within specifications. The damping mechanisms included eddy current damping due to magnet motions relative to the restrained SR aluminum chamber, structural damping in various bolted and welded pedestal-girder configurations, and damping pads and damped shear links. Various rubbers, corks, and viscoelastic materials (VEM) were tested as damping materials. An extensive series of vibration measurements was carried out which showed that the best results were obtained using VEM damping pads.

Several proprietary[4,5] acrylic polymers (3M ISD 112, 113, 468, 3127, 3128, and Anatrol 217, 218) were investigated for the damping pads' fabrication. These polymers are high energy dissipative materials that have been used widely for many years in aerospace, automotive, and electronic industries to solve complex vibration and noise problems. They are available in the form of double-sided, pressure-sensitive adhesive films with thickness in the 2-16 mils range. High energy dissipation in the small volume of a VEM film is, in most applications, due to high cyclic shear strains (up to 100%) that can be induced in the film when it is constrained between two surfaces in relative motion.

Material damping properties of a VEM are characterized by its shear modulus G (or Young's modulus E) and loss factor η. Stored energy in the VEM is proportional to G, whereas the fraction of stored energy that is dissipated by damping is proportional to η. Both of these properties are highly temperature and frequency dependent, a fact that must be taken into consideration when selecting a VEM for a specific application. This dependence is typically represented in a frequency-temperature plot such as one shown in Fig. 2 for Anatrol 217. To determine the material properties, a vertical line is drawn through a point intersecting the horizontal frequency line with the temperature isotherm. The intersection of this vertical line with the G and η curves yields the shear modulus and the loss factor at the selected frequency and temperature.

The performance of a VEM damping device (e.g., damping pads) depends not only on the material properties G and η, but also on the device's complex interaction with the structural system to be damped. The device is most effective when its dynamic interaction with the system produces large cyclic strains in the VEM. A system's loss factor is defined as the ratio of vibrational energy dissipated per cycle to the energy stored in all structural elements including the damping device. The inverse of this loss factor, denoted as Q, is a measure of the amplification of input motion (displacement) at resonance. Structural damping in bolted steel construction, such as a typical undamped girder-magnet assembly, results in a Q between 100 and 200. When using damping pads made of thick blocks of cork, a Q of approximately 30 was obtained for the SR girder-magnet assemblies. With the use of VEM damping pads, however, Q values ranging from 6 to 10 were easily achieved.

III. DAMPING PAD DESIGN

In addition to providing effective damping for the SR magnet vibrations, the damping pads were required to satisfy several design criteria. The pads were to be designed as passive and maintenance-free structural elements in order to assure high reliability in operation. They were not to interfere with the girder-magnet alignment, which was expected to be done frequently during the early SR installation and commissioning phases. Moreover, since a major portion of the SR was already complete, the damping pads' installation was to be performed in a way that required minimum displacement of the girder-magnet assemblies and no disconnection of the vacuum chamber bellows located between the girders.

These requirements led to a sandwich construction design for the damping pads. Essentially, the pads consist of VEM films sandwiched between two or more stainless steel plates, each with dimensions 0.070"(thick) x 8.5" (width) x 12" (length). Several VEM film thicknesses, varying from 2 to 12 mils, were used to optimize the damping performance. The five-plate pads provided better damping than the two- or three-plate pads. However, three-plate pad design with 6 mils Anatrol 217 VEM films, shown in Fig. 3, was eventually chosen for production as it provided the best cost-versus-performance solution.

Field installation of the damping pads requires the following simple steps. Mechanical jacks are placed between the girder pedestals to temporarily support the weight of the girder-magnet assembly. The heights of the wedge-jacks are then reduced to allow insertion of the damping pads between the wedge jacks and the pedestals. The wedge jacks are then extended to again support the girder-magnet assembly and the mechanical jacks are removed. During this operation, the girder's position does not change by more than 5 mils, which eliminates the need for breaking the bellows' connections between the vacuum chambers. Finally, the alignment is verified and fine adjustments are made, if necessary. The damping pads installation normally requires three hours per girder by a team of two technicians.

IV. DAMPING PAD PERFORMANCE

Figure 4 illustrates the performance of damping pads in the frequency range 4-50 Hz. The figure depicts pedestal-to-magnet amplification of radial (x) displacement amplitude for two girders: one in Sector 33 without damping pads (broken line) and another in Sector 35 with damping pads (solid line). The amplification peak at the first natural frequency, 9.5 Hz, is reduced from approximately 200 to 10. This corresponds to a reduction of Q from over 100 to 8. The damping pads tend to magnify the magnet response over 10 Hz. However, high frequency components of the ground motion usually damp very rapidly. At the APS, the magnet rms motion above 10 Hz accounts for less than 10 percent of the total motion in the 4-50 Hz band.

The effectiveness of damping pads under various floor vibration levels is shown in Fig. 5. For the two girders with and without the damping pads, the rms x-motions of the magnets is plotted against the rms x-motion of the floor. In general, the magnet motion without the damping pads is amplified by a factor of over 10, whereas the amplification factor with the damping pads is between 3 and 4. Under normal conditions (without construction and installation activities), the rms motion of the floor has been measured to be approximately 0.015 μm. This floor motion results in an rms motion of the magnets between 0.045 and 0.060 μm for girders with damping pads. Flow-induced vibration of the water headers increases the magnet rms motion by approximately 0.040 μm. The total magnet motion is still below its stringent specification of 0.11μm. Because of their location in the girder-magnet assembly, the damping pads provide only marginal damping to the flow-induced vibrations. However, it has been shown these vibrations can be reduced by a factor of 3 by rigidly supporting the water headers by the ceiling. The implementation of this solution is presently under consideration.

In another application, damping pads like the one shown in Fig. 3 were installed under the support table of the X-17 beamline monochromator at the National Synchrotron Light Source at Brookhaven National Laboratory. Time constraints during the maintenance period did not allow for preinstallation vibration tests to optimize the damping pads or to evaluate their performance quantitatively. Nevertheless, a substantial qualitative improvement was observed in the monochromator's vibration response [3]. In subsequent tests, a Q of 25 was measured at the monochromator housing, as compared to an expected value of over 100 for an assembly of undamped steel components.

V. RADIATION AND CREEP EFFECTS

There were two main concerns regarding the use of the VEM damping pads under the SR girder-magnet assemblies. First, the damping pads will be subjected to a radiation dose of up to 10^6 rads during their lifetime (approximately 30 years). Radiation exposure on a VEM can adversely affect its damping properties due to a complex combination of scission of long molecular chains and crosslinking. Secondly, under the combined weight of the girder and the magnets, the VEM films are subjected to an average static pressure of 50 psi. The potential creep damage to the viscous films can degrade their damping properties.

Several experiments were carried out to measure the effects of radiation and creep on the candidate damping materials. The material properties were characterized by using the vibrating beam technique following ASTM Standard E-756. A cobalt 60 source was used to obtain radiation exposures ranging from 10^5 to 10^8 rads. Accelerated creep tests at elevated temperatures were performed to compress the time scale using the time-temperature equivalence principle.

The results of these experiments[6] showed that no significant variation in the damping properties of a VEM can be expected during the operating conditions of the APS storage ring. Field measurements, performed with damping pads already exposed to radiation and creep, also verified that the Q values changed insignificantly within the scatter of measurement errors.

VI. CONCLUSIONS

Viscoelastic damping pads have been shown to provide an attractive and cost-effective solution for passive vibration control of accelerator and beamline components. At the APS the damping pads reduced Q of the storage ring girder-magnet assemblies from over 100 to 8, and their use proved to be essential in meeting the stringent vibration specification. The simple design of the pads allows for their easy in-situ installation without interference with the alignment or vacuum connections of the components. Radiation and creep effects on the damping performance of the viscoelastic pads were found to be insignificant.

ACKNOWLEDGEMENT

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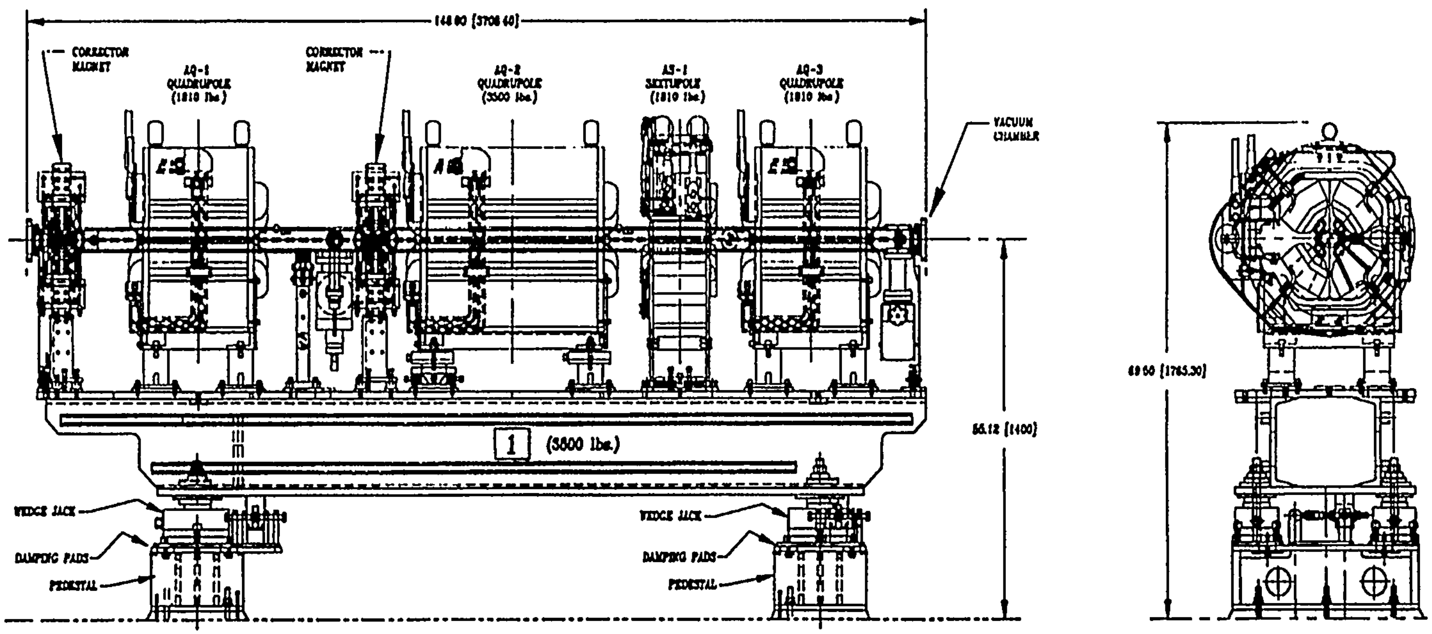

Fig. 1. APS Storage Ring Girder Number 1 Assembly.

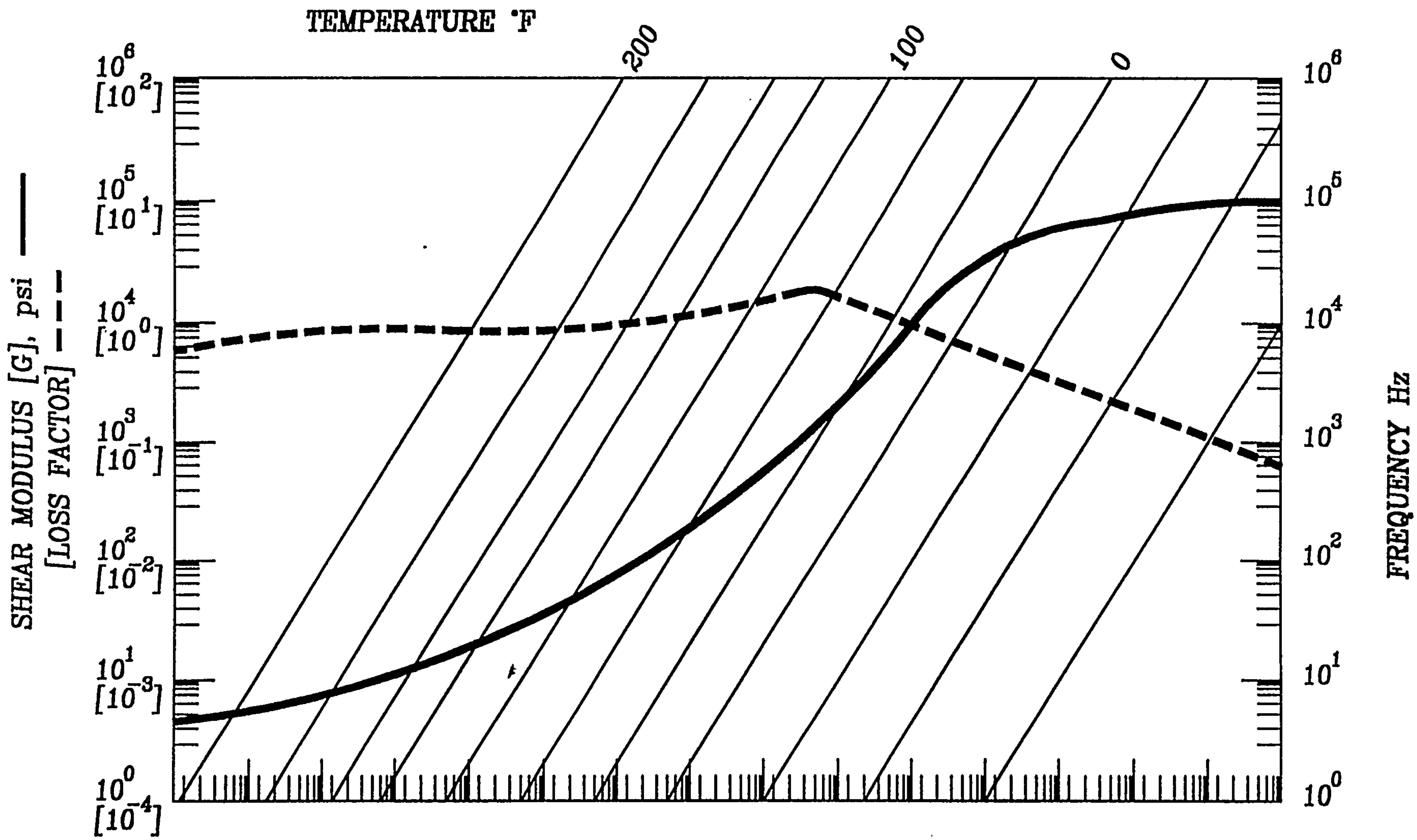

FIG 2 ANATROL 217 VISCO ELASTIC DAMPING MATERIAL

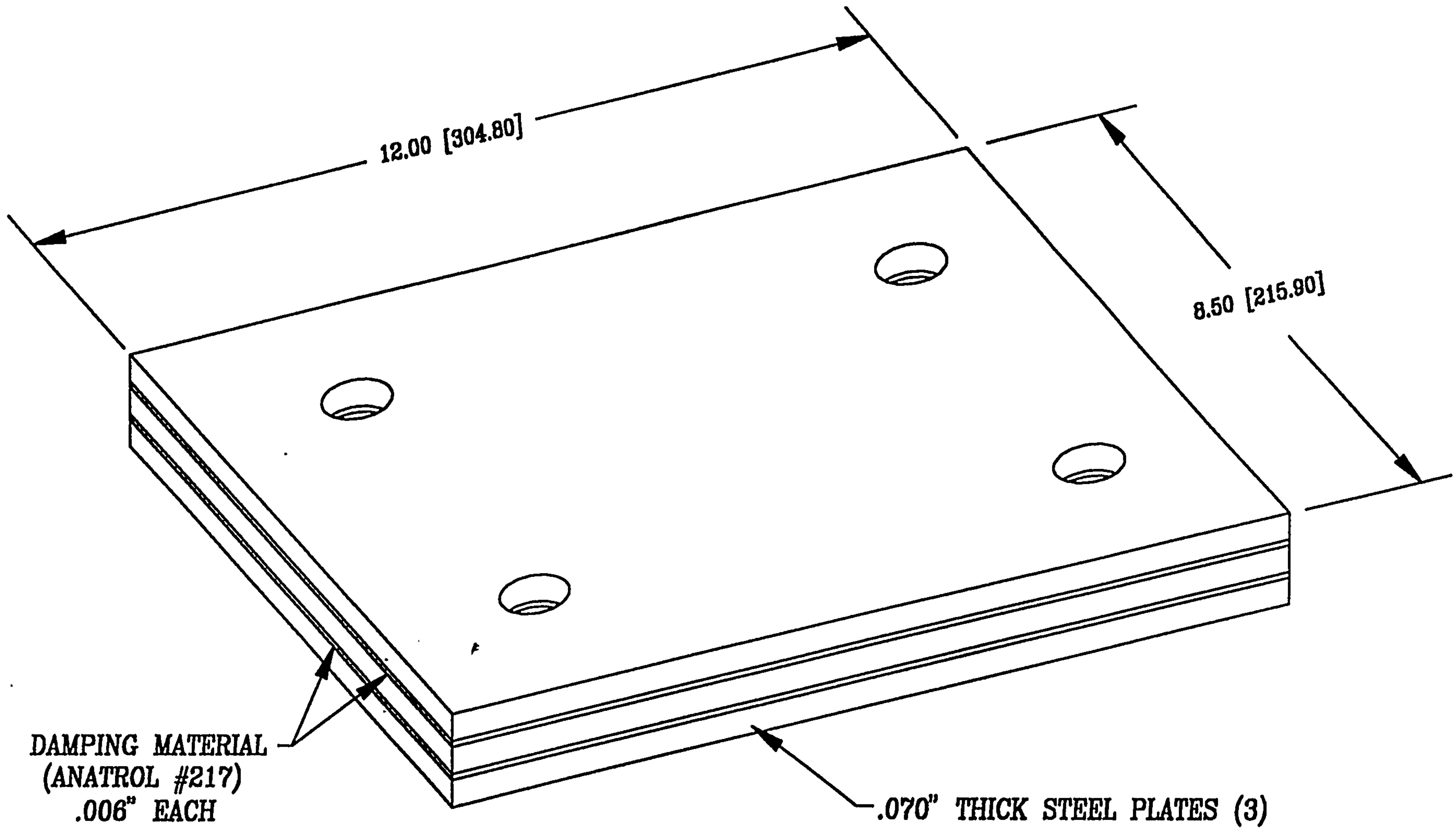

FIG 3 LAMINATED DAMPING PAD

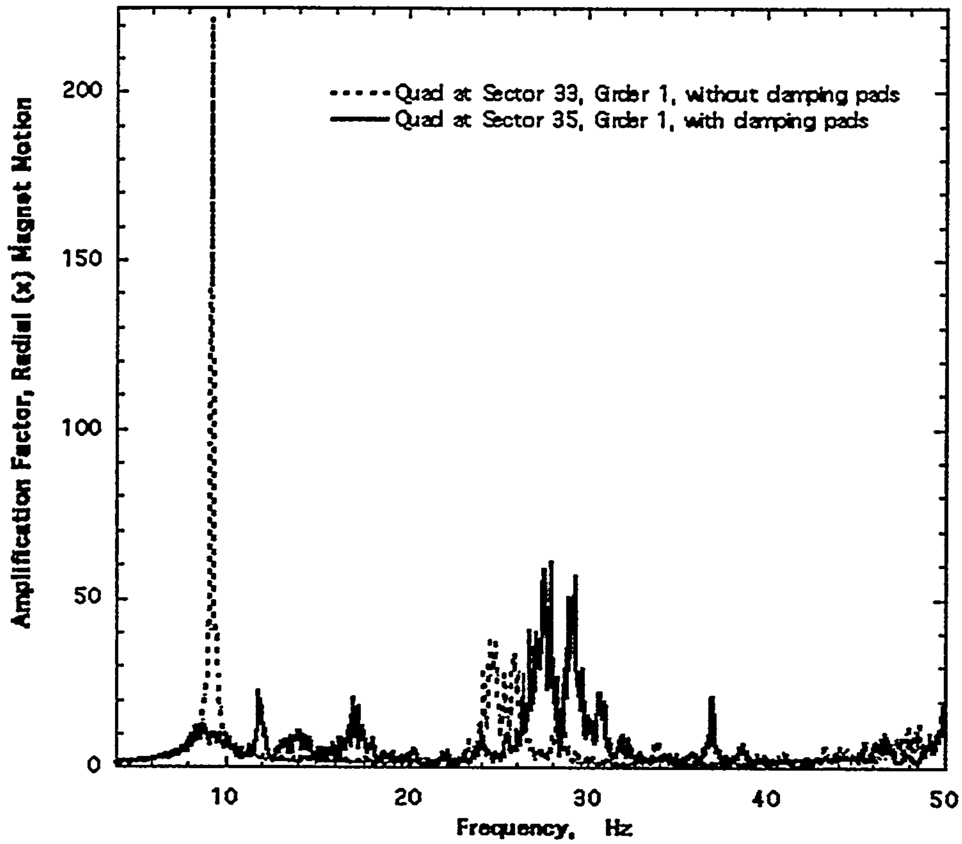

Fig. 4. Amplification of Radial (x) Magnet Motion with and without Damping Pads

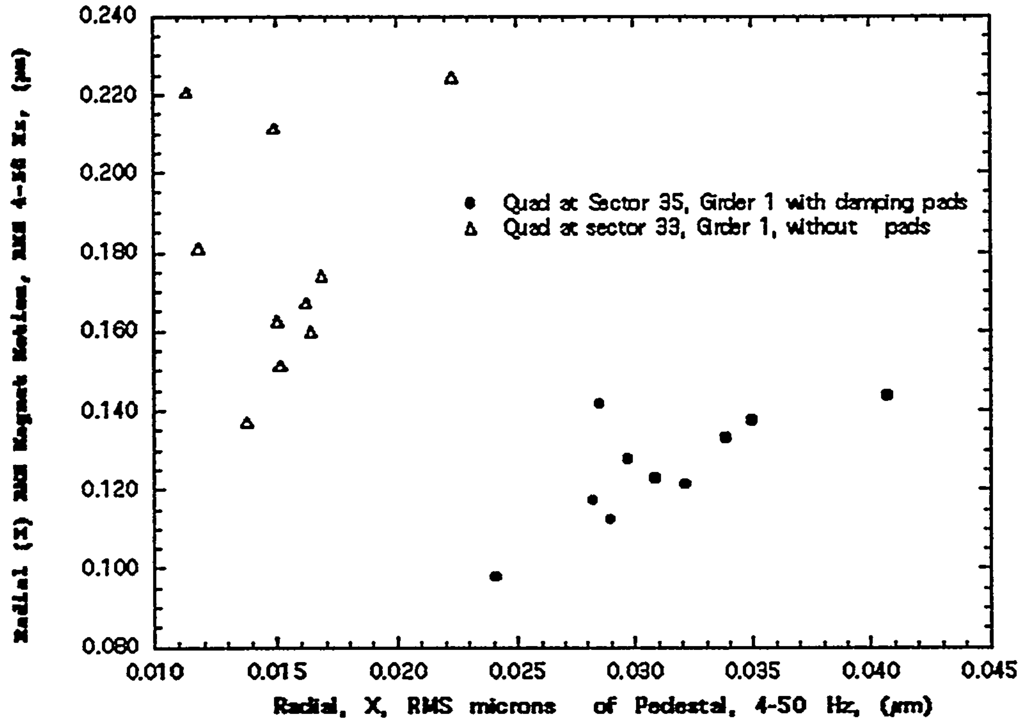

Fig. 5. Radial (x) Magnet Motion in 4-50 Hz with and without Damping Pads