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BRINGING THE GROUND UP (WHEN IS TWO LESS THAN ONE?)

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Abstract

The Advanced Photon Source Upgrade (APSU) project has employed the use of high-heat-load dual-mirror systems in the new feature beamlines being built. Due to the shallow operating angles of the mirrors at a particular beamline, XPCS, the two mirrors needed to be approximately 2.5 m apart to create a distinct offset. Two separate mirror tanks are used for this system. However, it is unclear if the vibrational performance of these tanks would be better if they were both mounted on one large plinth or each mounted on a small plinth. Using accelerometers at the installation location, the floor vibrations were measured. The resulting frequency response function was then imported into a finite element analysis software to generate a harmonic response analysis. The two different plinth schemes were modeled, and the floor vibration was introduced as an excitation to the analysis. The relative pitch angle (θ_Y) between the mirrors was evaluated as well as the relative gap between the mirrors (X_{MAG}). Results showed that a single plinth reduces the relative X_{MAG} (RMS) compared to two plinths by approximately 25%. However, the relative θ_Y (RMS), which is arguably more critical, is significantly lower by approximately 99.7% in two plinths when compared to a single plinth. Therefore, it is more effective to use two separate plinths over a longer distance as opposed to a single longer granite plinth.

INTRODUCTION

Floor and support vibrations can introduce unwanted motion in a beamline. Optics, such as mirrors, are especially sensitive to these vibrations as they operate at small angles. Small variations in the angle can propagate into large errors over a distance of several meters. Therefore, it is important to design support structures that minimize these vibrations.

In the case of the XPCS beamline at APSU, the high-heat-load dual-mirror system operates at a shallow angle, and to create a distinct offset, the mirrors must be separated by 2.5 m along the beam direction. The question arose whether having the mirror tanks share one large granite plinth as a base would be better to minimize vibrations or would it be better to use two smaller granite plinths, one for each mirror tank.

Definition of Parameters

Two important parameters affect the beam position and energy range. To better illustrate, a top-down view of the mirrors is shown in Fig. 1.

Figure 1: Top-down view of mirrors showing 0° angle with respect to the beam (dotted line). Beam travels left to right. The first mirror is called M1 and the second mirror is M2.

The first parameter of interest is the relative gap between the mirrors (X_{MAG}). X_{MAG} can affect the offset beam position downstream of the mirror system as it may cause the beam to wander along the X direction. Ideally the X_{MAG} should be zero.

Using the absolute motion of each mirror as shown in Fig. 2, the relative gap can be calculated:

$$X_{MAG} = X_1 - X_2 \,.$$

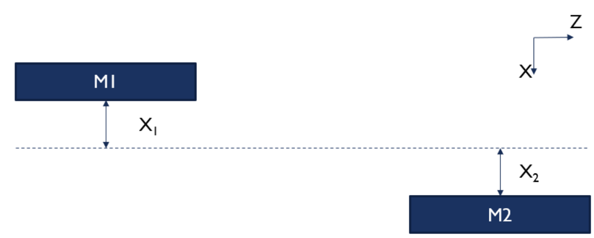

Figure 2: Top-down view of the mirror system showing absolute motion of each mirror with respect to the beam in the X direction.

The second parameter of interest is the relative pitch angle between the mirrors (θ_Y). The relative pitch angle is more critical as it can affect the energy range of the beam passing through the mirror system as well as reduce its effectiveness at absorbing high heat load from the white beam. Ideally θ_Y should be zero.

Using the absolute pitch angle of each mirror as shown in Fig. 3, the relative pitch angle can be calculated:

$$\theta_Y = \theta_1 - \theta_2 \,.$$

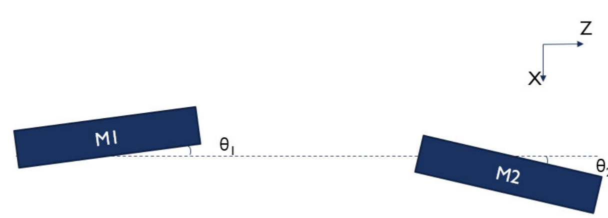

Figure 3: Top-down view of the mirror system showing the absolute pitch angle of each mirror with respect to the beam. Pitch angle is considered rotation about the Y axis coming out of the page.

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METHODOLOGY

Floor Vibration Measurements

To best model these parameters, accelerometers were used at the installation location to measure floor vibrations. Two sets of tri-axial accelerometers were used for these measurements. Each set was oriented to measure vibrations in the beam coordinate system, where Z is along the beam, X is orthogonal to the beam and parallel to the ground, and Y is orthogonal to the beam and the ground as shown in Fig. 4.

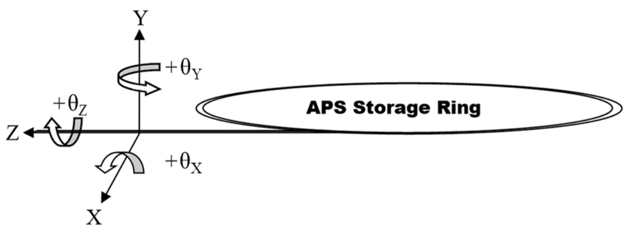

Figure 4: APSU beamline coordinate system.

One set of accelerometers was placed at 28 meters and the second set was placed at 30.4 meters, each with respect to the beam source as shown in Fig. 5. Existing installed components prevented the placement of the accelerometers at exactly 2.5 m apart, but the small error does not impact the overall measurements.

Figure 5: Placement of tri-axial accelerometers on the installation site with respect to the beam source.

The accelerometers measured vibrations from 1.5 Hz to 200 Hz. At the APS, floor vibrations beyond 100 Hz are negligible in amplitude and are therefore not a concern. However, for the purpose of the study, the bandwidth goes up to 200 Hz.

Finite Element Analysis

Once the measurements were taken, two finite element analysis studies were generated using ANSYS to measure the effects of the floor vibrations on the two parameters. The first study used the case of a single large granite plinth while the second used two smaller granite plinths.

For the first study, three steel plates were bonded to the base of the granite, which were then subsequently bounded to a grout material. The frequency response function (FRF) from each accelerometer was applied to the grouted plates at either end of the granite plinth. An average of the FRF data was applied to the center grouted plate. A point mass distributed the weight of two mirror tanks across the top surface of the granite plinth as shown in Fig. 6.

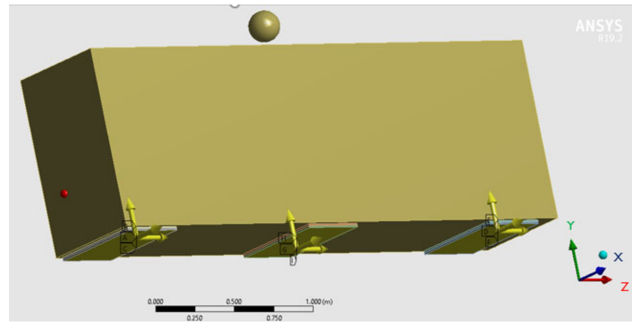

Figure 6: First study, single large granite plinth showing three grouted plates along the bottom and a point mass distributing mass across the top surface.

For the second study, each smaller granite plinth had two grouted plates (same as the first study) on either end of the plinth base. The individual mirror tank mass was applied as a point mass on each granite plinth surface as shown in Fig. 7. The FRF data from one set of accelerometers was applied to both grouted plates on one granite plinth and the other data set was applied to the second granite plinth.

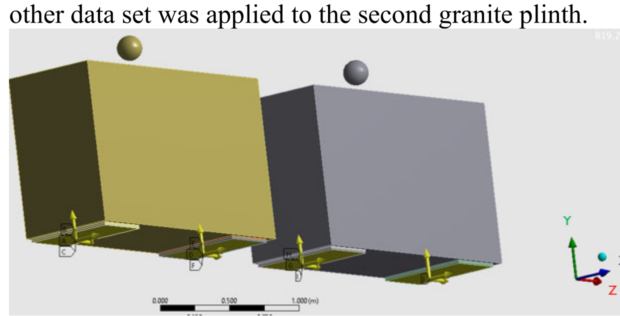

Figure 7: Second study, two smaller granite plinths showing four grouted plates along the bottom and a point mass distributing mass across each granite top surface.

The displacement of the mirror centers along the X direction was extracted, along with the rotation of the mirror centers about the Y direction. They were then used to calculate the RMS values of X_{MAG} and θ_Y.

RESULTS

The ANSYS data was processed using a custom MATLAB script. The relative pitch angle and relative gap were processed for each study and graphs were plotted in Fig. 8 along with their RMS values across the frequency bandwidth. The values are summarized in Table 1.

Table 1: Summary of Relative Stability

Study	θY (RMS)	XMAG (RMS)
One Plinth	1.2 nrad	2.6 nm
Two Plinths	0.0042 nrad	3.4 nm

The results showed that using a single plinth reduced X_{MAG} by 25% compared to the two plinths case. However, θ_Y was reduced by three orders of magnitude in the two plinths case when compared to the single plinth case. As this is the more critical parameter, the results show that two smaller plinths are the better option to reduce vibration motion.

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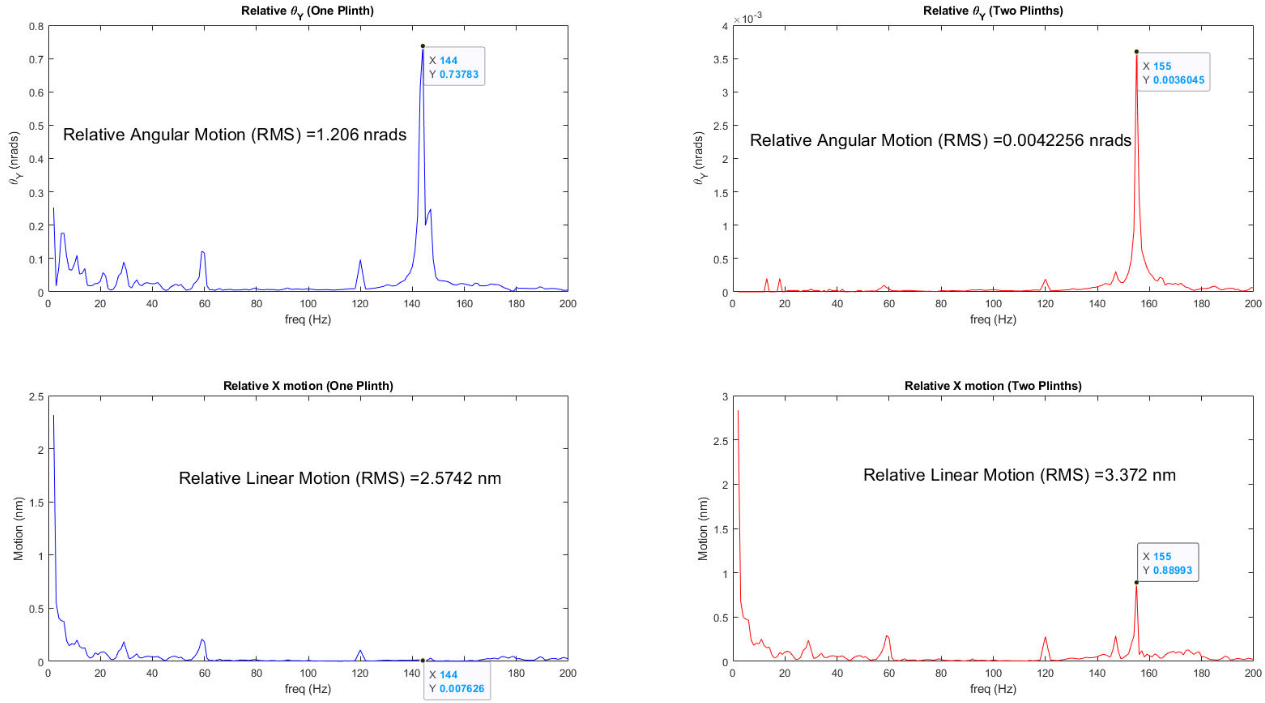

Figure 8: Plots of X_{MAG} and θ_Y in both studies across the frequency bandwidth.

CONCLUSION

The results in this paper show a clear distinction between using two smaller granite plinths versus one large granite plinth. This was contrary to the initial assumption that using a single large base would move the mirror optics uniformly. The improved performance for X_{MAG} shows that a single granite plinth does move the mirrors together better. However, due to the large distance between the mirrors, their relative pitch errors can add up to yield much larger values. As this is the critical dimension, it is more effective to use two smaller granite plinths. The smaller granite plinths also aid in the ease of installation when maneuvering around the installation site compared to moving one larger and heavier piece.

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