Vibration measurement and analysis techniques: x-ray beamline vibration diagnosis at the APS

C. Preissner and D. Shu
APS Engineering Support Division
Argonne National Laboratory, Argonne, IL 60439, USA

Abstract

Low-level vibration measurement and analysis are becoming more important in the operation and servicing of x-ray beamlines. State-of-the-art x-ray optics are routinely producing effective beam spot sizes of a few tens of nanometers, placing extreme requirements on the beamline support structures. As the x-ray optic performance has increased, demand for vibration measurements and data analyses has increased.

This paper reviews the Advanced Photon Source beamline engineers' accumulated experience in the vibration measurement and diagnoses of x-ray beamline equipment, particularly with low-level vibrations. Areas to be addressed include low-level measurements, transducer selection, transducer mounting, signal conditioning, and data acquisition. Specific measurement case studies will include two monochromators.

1. Introduction

Since the inception of the Advanced Photon Source, microfocusing and microdiffraction techniques become de rigueur around the APS and vibration measurements of optics support structures and endstation equipment has become more necessary. Throughout the same time period, data acquisition and vibration measurement equipment have become much more accessible to the general audience by the advent of low cost PC based digitization devices and the availability of inexpensive piezoelectric transducers. However, along with the standard vibration measurement considerations, some special characteristics of the APS vibration environment make successful vibration *analysis* more than making a *measurement* by connecting an accelerometer to a data acquisition device and clicking the start button.

Basic considerations when preparing to make any vibration measurement include: transducer sensitivity, mounting method, transducer mass, and sampling parameters. The distinctive issues to be considered when considering vibration analysis of beamlines are: low vibration level and vacuum hygiene. The matter of making measurements on a vacuum sensitive device requires appropriate mounting and handling of the transducer and cabling.

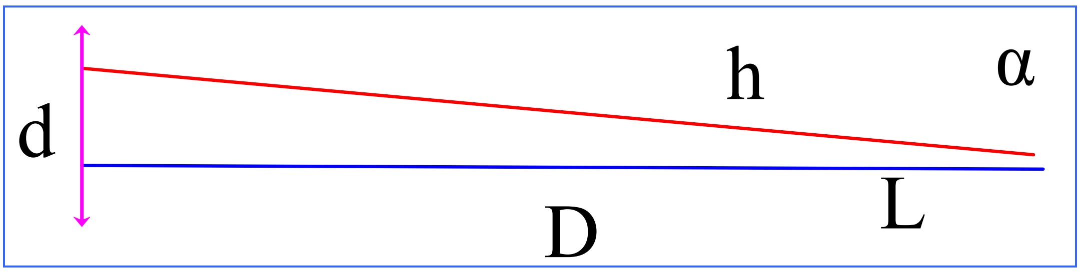


Figure 1. Geometery of typical beamline

D = distance from experiment location

d = beam movement at experiment location

L = length of optic element or structure

α = angle of rotation of structure

h = amplitude of vibration on structure

The problem of low level vibration requires a very electrically quiet and sensitive transducer coupled with quiet amplification and data acquisition. Figure 1 illustrates the necessity for low level measurements. Consider a generic beamline with an experiment located **D**=10m away from an optic element. If the beam motion, **d**, is equal to 1×10-6 m, the angular motion of the optic element, **α**, associated with this beam displacement will be about 1×10-6 radians. If the optic is 10×10-2 m long, the displacement of one end of the device will be about **10×10-9 m**. This idea along with the generally low floor vibration (~10nm from 1-20 Hz) found around the experimental floor, calls for the use of a measurement system that can measure displacement on the order of tens of nanometers or less.

2. Transducer considerations

The low vibration levels dictate the use of high sensitivity accelerometers, although choosing the best is not as simple as selecting the most sensitive. The vibration transducer of choice is the piezoelectric accelerometer. As the name indicates this device has a piezoceramic element that provides a signal output proportional to acceleration. The piezo element is clamped between a seismic mass and the transducer base. Vibration of the transducer accelerates the seismic mass causing a strain in the piezo crystal. The required sensitivity, transducer size, and mounting method all need to be considered when making low level measurements on beamline equipment

- Sensitivity
  - As mentioned above, the transducer sensitivity should be large, around 7-10 V/m/s2.
  - Due to the principle of operation, transducers with high low frequency sensitivity will tend to be larger, electrically quieter and have lower resonant frequencies than less sensitive transducers.
  - The combined transducer and amplifier sensitivity should be around 700 V/m/s2; this will provide sufficient low frequency signal amplitude.
- Size/mass
  - The mass of the transducer should not exceed 1/10 of the mass of the substructure that it is mounted to, otherwise the transducer will have a significant effect on structure dynamics.
  - Increased transducer mass will affect the mounting method.
- Mounting
  - The best method of mounting the transducer is by using a threaded stud with smooth mating surfaces between the accelerometer and the structure, for large transducers, >0.4 kg, this will provide mounting frequency above 5 kHz. However…
  - The most common mounting method is wax, but care needs to be taken in having the thinnest layer of wax possible. Wax mounting natural frequency drops when the temperature and thickness of the wax increases. The mounting natural frequency of a group of three large high sensistivity accelerometers, as shown below, will be around 2.9 kHz.
  - Wax cannot be used on vacuum sensitive equipment so the preferred mounting method is with a mechanical fastener using an intermediate bracket.

	These properties tend to change:				
As this property increases:	**Sesitivity**	**Size**	**Mass**	**Noise**	**Time Constant**
Sensitivity		↑	↑	↓	↑
Size	↑		↑	↓	↑
Mass	↑	↑		↓	↑
Noise	↓	↑	↑		↓

3. Data acquisition

The equipment used to record the data should provide an accurate means of sampling the transducer signal and a convenient method of storing the data for either manipulation on the recording device or processing offline. Three important areas to consider are the digitization, the measurement parameters, and the signal conditioning. A typical piece of vibration measurement equipment will have a analog to digital converter (ADC) with necessary filtering, selectable bandwidth and sampling resolution, and built in fast fourier transform (FFT) capability along with data storage to disk.

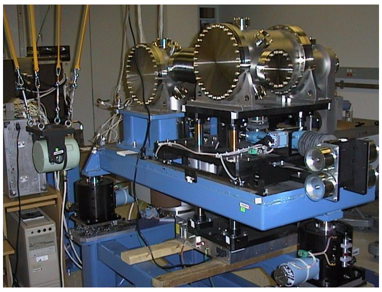
- Digitization
  - An analog antialiasing filter should be present—all vibration specific equipment will have this.
  - The ADC should have a large dynamic range, allowing for good amplitude resolution even if transient signals are expected.
  - The ADC should have multiple input ranges to achieve the best possible amplitude resolution.
- Signal conditioning
  - Transducers with built in voltage following amplifiers are preferred, (ICP, Isotron, etc…), because they are less susceptible to cabling noise.
  - Battery powered transducer power supplies and amplifiers are proffered because of the low noise, less chance of coupling into power line noise, and the ability to use high gain (due to the low noise).
- Measurement parameters
  - Frequency domain measurements are a very useful way to display vibration data, however don't overlook the time domain. Observing the time domain signal may help catch possible errors due to saturation of the transducer or amp, clipping due to insufficient ADC range, or just additional insight into the vibration problem. In addition the time domain signal can be used to calculate the band limited RMS vibration level.
  - Time domain measurements should be considered especially when measuring transient responses.
  - When making frequency domain measurements, select a measurement bandwidth that has the largest appropriate frequency resolution to minimize the length of the time record, but still allow for resolution of close peaks in the spectrum.

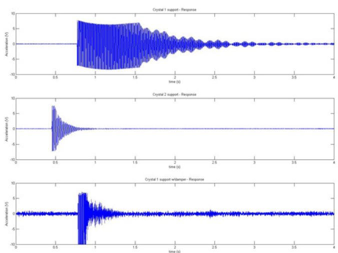
4. Case studies

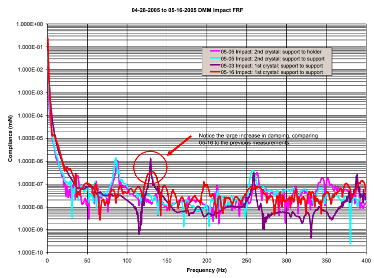
1.1. Case study 1:

Large X-ray beam motion was observed in sector 2 when the double multilayer monochromator (DMM) was in service. A careful vibration survey was performed on the instrument.

- Measurements were made using large high sensitivity accelerometers to quantify the vibration amplitude and the frequency response of the support structure.
- Measurements were made in the vacuum tanks of the crystal support structures using small high sensitivity accelerometers. It was determined the problem was caused by a highly resonant first crystal support structure.
- *Time* and *frequency* domain data were analyzed to determine the location in the frequency spectrum and estimate the damping.
- A friction based damper was used to increase damping and reduce the response of the 1st crystal support structure, as shown by the time domain and frequency response data in figure 2.



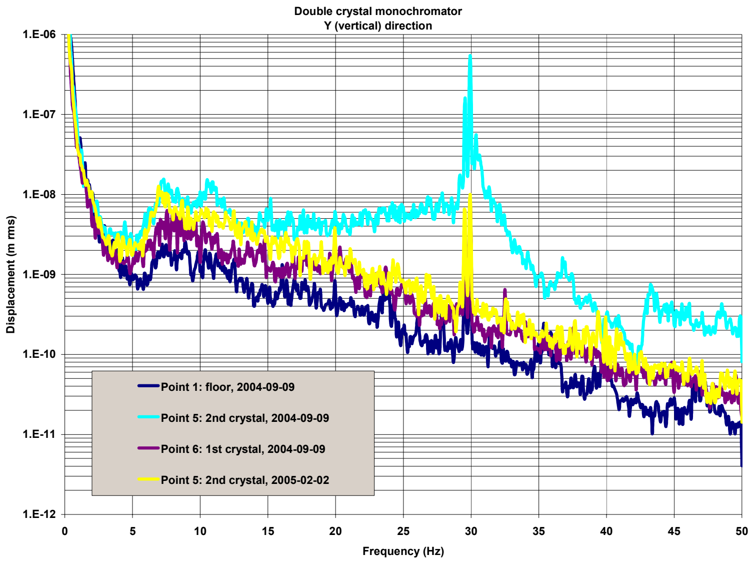




1.2. Case study 2:

A bioscience beamline was using an externally designed double crystal monochrmator on a crystallography beamline. Beam stability at the sample position was an issue and the problem was tracked to the monochromator. Vibration of the second crystal holder was found to be in excess of 500nm.

- Power spectrum and frequency response functions were measured at between the different motion components of the system. Subsequent analysis revealed the problem to be specific to the second crystal holder.
- The structure appeared to be very susceptible to ≈30Hz input. Harmonics of the power supply voltage should be carefully considered as to the origin– actual mechanical phenomenon, or electrical artifact. We then made a careful inspection of the measurement system to rule out electrical noise. It was concluded that this APS sector has increased floor vibration due to some AC motor source.
- Our measurements were used by the manufacturer to corroborate their measurement results on a similar device in the manufacturer’s laboratory.
- The manufacturer made structural improvements to the second crystal holder. When the new components were installed, we assisted with the verification that the new pieces eliminated the problem, results are shown in figure 3.



5. Conclusion

Each vibration diagnosis situation is unique and should be treated as such. However, consistent application of the above mentioned considerations should result in the acquisition of meaningful data, enabling the engineer to analyze and solve the problem. Particular attention should be paid to transducer selection and verification of transducer performance.