Tests of White Beam Motions

Alan Kastengren, X-Ray Science Division
Katie Matusik, Brandon Sforzo, Energy Systems Division

Tests were recently conducted at 7-BM to understand the extent and frequency of motions of the white beam. A better understanding of such motions is needed to better understand the sources of beam motion in focused beam experiments, fluctuations in intensity in time-resolved radiography, and motions of structure in the beam. It is also important for understanding the improvement that may be expected from efforts to improve the stability of beamline optics.

Even minor motions of the source point can be problematic for time-resolved measurements. For high-speed phase-contrast imaging, source point motions will shift the position of features in the image. While these shifts will be slight, they can be noticeable, particularly when trying to subtract a background to see subtle features in images.

Experimental Setup

This experiment was based on direct imaging of the white beam performed at 7-BM. The overall optical setup is a fairly standard indirect-detection system used at many beamlines at the APS. The white beam was stopped down to 100 x 500 microns size at the beamline white beam slits, located approximately 22.6 m from the source. The beam was filtered with a 50 micron thick copper filter, then passed into 7-BM-B. The beam illuminated a 100 micron thick LuAG:Ce scintillator placed 35.3 m from the BM source. The resulting light was reflected 90 degrees with a mirror and imaged with a Mitutoyo 5x microscope objective connected to a Photron SA-4 high-speed camera (20 micron pixel size). Images were collected at 30 kHz with a 25 μs exposure time. A total of 51743 images were taken. An example image is shown in Fig. 1.

In principle, the experimental setup is a crude pinhole camera, though in this case the ‘pinhole’ is larger than the source being imaged. Given the small size of the slit compared to the BM fan, both vertically and horizontally, motions of the beam on the imaging system should represent motions of the x-ray source point, rather than variations in the direction of beam propagation from the source. Given the relative positions of the source, slits, and imaging system, the motions of the source point are 1.78 times larger than the motions of the imaged beam listed below.

Analysis

To analyze the beam motion in the y (vertical) direction, all columns of each image were summed together. The dark background was subtracted away, and the center of mass of the image was recorded. After processing all images, this resulted in a time record of beam motion. A similar analysis was performed for x (horizontal) motions. These motions were then analyzed to produce power spectra of the motions using standard Fourier transform methods, with the time series split into 4096 sample length sections and the power spectra of these sections averaged. This gives an effective frequency resolution of 7.3 Hz.

Limitations

In the following analysis, it is assumed that the imaging system and white beam slits are fixed. It is of course possible that some of the apparent beam motion is due to vibrations of these components, though such vibrations are believed to be quite small. The limited sampling frequency (15 kHz Nyquist frequency) and lack of suitable methods to anti-alias imaging data leaves the possibility of aliasing in the data. The limited time duration of the test (< 2 s) limits the frequency resolution of the spectral analysis. A longer time record would allow for better frequency resolution and lower noise in the power spectra.

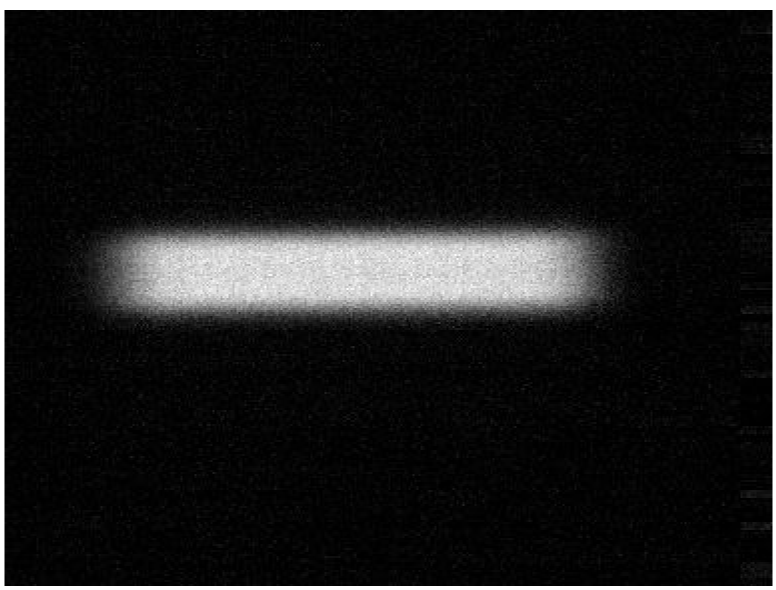

Fig. 1: Example image of the white beam.

Results

Figures 2 - 4 show the results of analysis of the vertical motions. The overall standard deviation in beam position was 2.2 microns. Figure 2 shows a log-log plot of spectral density vs. frequency, with Fig. 3 showing the same data on a semilog scale. The most prominent frequencies are around 58-60 Hz, 147 Hz, and 180 Hz. There are other discrete frequencies, particularly at 360, 512, and 720 Hz, though the motions in these regions are quite small compared to the motions at the aforementioned predominant frequencies. This can be seen quite clearly in Fig. 3. Subsequent imaging of the beam passing through the beamline monochromator showed no strong fluctuations at 180 Hz; the cause for this difference is unknown.

Figure 4 shows the cumulative variance in the beam position as one integrates from low frequencies to high. The majority of the vertical beam motions are found between 100 and 200 Hz. It should be noted that beam fluctuations at 147 Hz have been found in the beamline characterization work performed by Ruben Reninger and Xianbo Shi over the past few years, as well as in high-speed XPCS work at 8-ID.

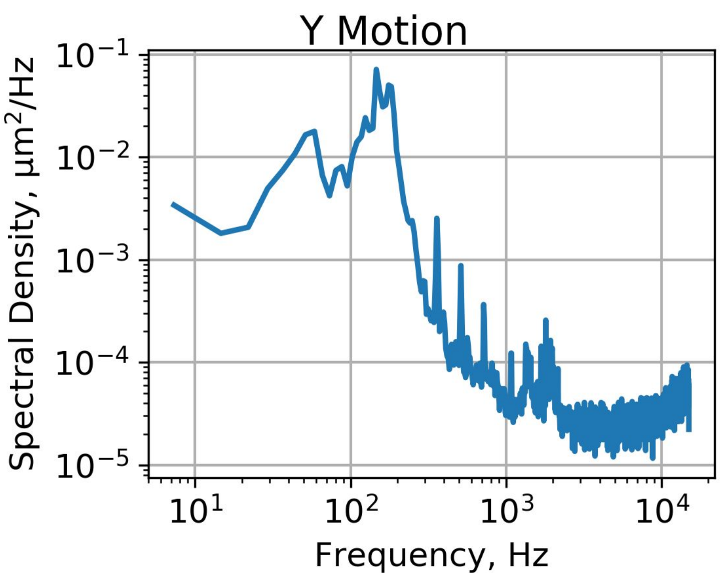

Fig. 2: Log-log plot of vertical beam motion spectral density vs. frequency

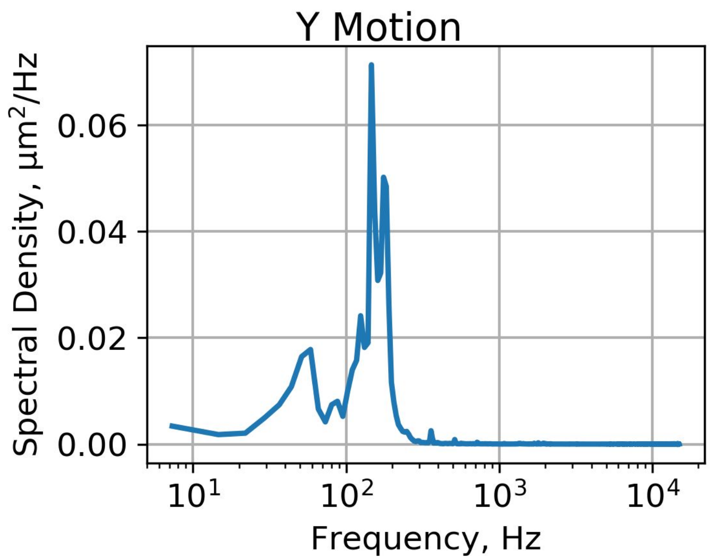

Fig. 3: Semilog plot of vertical beam motion spectral density vs. frequency

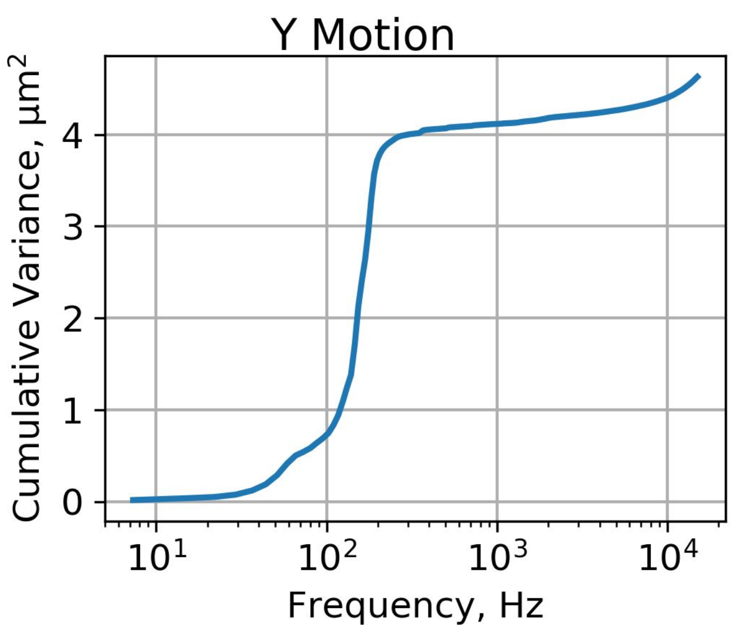

Fig. 4: Cumulative variance in vertical beam position, integrated from low frequencies to high.

Figures 5-7 show similar plots for the horizontal motions. The standard deviation of the horizontal motion was 1.69 microns. The motions in the x direction are more complex than in the y direction. The peaks seen in the y motion at around 58-60 and 147 Hz are still evident. The strongest peak is at 360 Hz, with another more diffuse peak at around 2 kHz. The cumulative plot of variance shows that the motions at 360 Hz and 2 kHz are major contributors to the horizontal motion.

While the resolution at low frequencies is poor in these measurements, it should be noted that similar imaging at lower frame rates and with a longer time record of the beam reflected from the 7-BM multilayer monochromator showed very few frequency components at less than 30 Hz in either direction, and it is suspected that most of the components found at less than 50 Hz are due to vibrations of the optics inside the monochromator. The stability of the x-ray source point at < 30 Hz appears to be quite good.

In conclusion, significant x-ray source point motions appear to be present in the BM white beam, and these motions occur at specific, well-defined frequencies. Frequency components at 58-60 Hz and 147 Hz appear to affect both the vertical and horizontal motions. Motions at 360 Hz and around 2 kHz are significant components of horizontal source point motion.

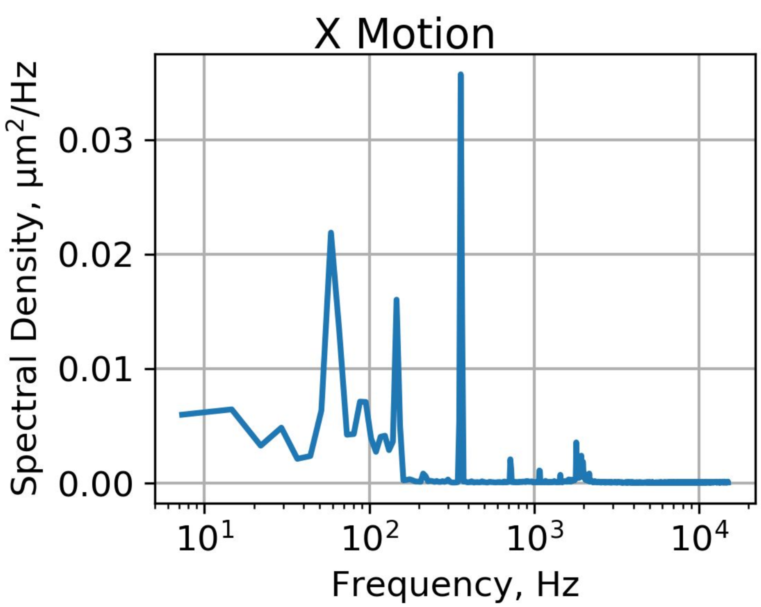

Fig. 5: Log-log plot of horizontal beam motion spectral density vs. frequency

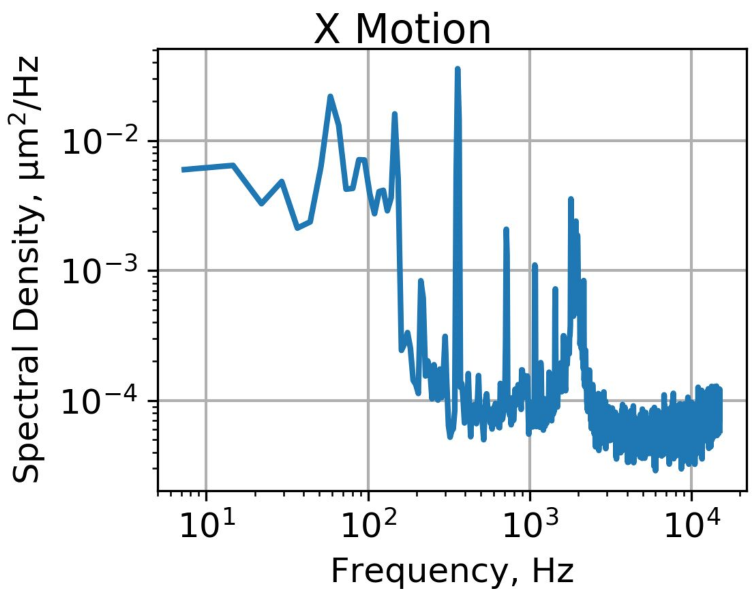

Fig. 6: Semilog plot of horizontal beam motion spectral density vs. frequency

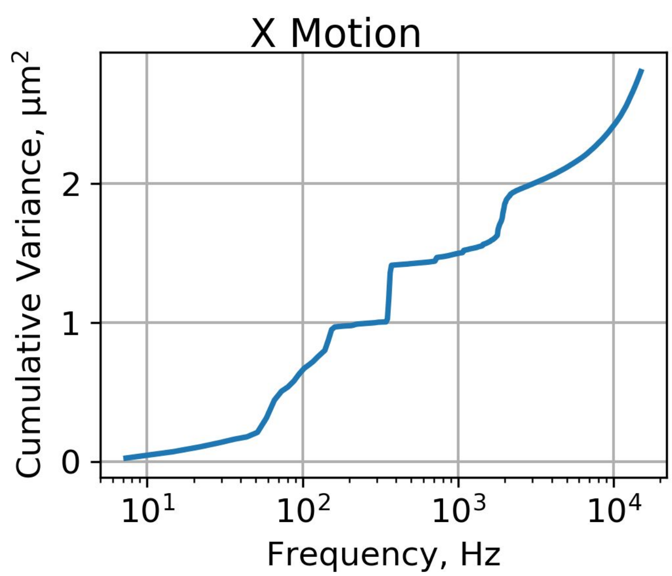

Fig. 7: Cumulative variance in horizontal beam position, integrated from low frequencies to high.