DESY Summer Student Program 2010

Work Report

Vibrations at PETRA III

Frederik Vanmeert

Universiteit Antwerpen

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Supervisor: Dr. Gerald Falkenberg , Dr. Gerd Wellenreuther

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Acknowledgements

I would like to thank the organization behind the DESY Summer Student Program for giving me the opportunity to participate in this program. I think it is safe to say that I learned a lot during these past two months. I would also like to thank my supervisor Gerd Wellenreuther for the great enthusiasm with which he has guided me throughout the program. It has been a great experience working with him. I thank Gerald Falkenberg for having me in his group as well as the rest of the P06 group and all the other people that I worked with during my stay.

Summary

I worked in the group of the Hard X-Ray Micro/Nano-Probe beamline (P06) at PETRA III. As this group will be working with nanobeams, they have a natural interest in studying the vibrations at their beamline and in the experimental hall in general.

My project can be divided into two parts. The first part deals with programming in Python. As I was not familiar with the Python programming language I first worked through some Python tutorials. I was asked to write a script that would deal with the growing amount of data coming from a permanent seismometer. This seismometer is placed behind the control hutch of P05. The script would need to be able to automatically process raw data, archive old raw data and delete old *.png files, which are a result of the analysis. I also made some minor improvements to the script that evaluates the vibration data.

As a second part of my project, I did several vibration measurements. I did a measurement to compare the signal coming from the seismometer with the signals coming from two accelerometers which I used during the rest of the vibration measurements. These accelerometers were used to measure the vibration stability of the granite tables in the experimental hutch of P11, in the nanofocus hutch of P06 and outside air condition hutch 1 of P04. The effect of the newly opened bridge over the experimental floor of the PETRA III hall was measured.

1. Introduction

As most of the beamlines of PETRA III will go for some degree of focusing (ranging from micrometers to several 10 nanometers), vibrations are of great concern. These vibrations can come from seismic movement, cultural noise (e.g. traffic) and from activities on the experimental floor itself. When experiments are being conducted with very small focal spot sizes (< 100 nm) it is crucial that both the position of the beam, as well as the position of the sample remain unchanged (or at least unchanged in respect to each other). Therefore vibrations which cause movements down to the nanometer scale become unwanted.

To reduce the amount of vibrations, a lot of effort was put into constructing a “near vibration free” floor. To achieve this, the roof of the experimental hall and the overhead 20 ton crane are being carried by 20 m long columns. These columns are supposed to transfer all forces 15 m deep below ground level. In between the two rows of columns, the 7000 m^2, 1 m thick concrete base for the experiments should rest undisturbed on the sub-soil. This base had to be cast as one monolithic piece in order to meet the mechanical specifications for all experiments and the storage ring inside the new PETRA III experimental hall.[1]

To monitor the vibrations of the experimental floor, a permanent seismometer (CMG-T30, Güralp Systems) is already in place behind the control hutch of P05. The data from this seismometer will give “real-time” information on the vibrations of the experimental floor, which is useful during experiments in the different beamlines. Plans are being made for the use of a second seismometer for the same purpose. Additionally two accelerometers (SF3000L, Colibrys) are being used to test experimental tables, investigate the effect of local vibration sources (e.g. pumps), etc.

The project that I was working on during the DESY Summer Student Program 2010 deals with these ongoing vibration measurements.

2. *Programming in Python*

2.1. Python

Python[2] is a powerful, easy to learn, open source programming language, whose design philosophy emphasizes readability. Thanks to the availability of libraries like Numpy, SciPy and Matplotlib, Python can be used effectively in scientific programming. To familiarize myself with this programming language, I worked through some online tutorials[3] as well as the first chapters of *Dive into Python*[4].

2.2. Seismometer script

A permanent seismometer has been installed in the new PETRA III hall to monitor the vibrations of the ca. 7000 m^2 large experimental floor. This seismometer uses a sampling rate of 200 Hz and creates an ASCII dataset (*.ufa) per minute measured. To fulfill the task of a monitoring system, meaningful information should be extracted from the raw data in "real time". Furthermore, a solution had to be found to deal with the ever-growing amount of data coming from the seismometer.

There were already two scripts to deal with these tasks: a script that processes the raw data per complete hour and a script that compresses the raw data to a *.rar file. I rewrote the script in charge of the evaluation to let it evaluate packages of both 5 minutes worth of data and of one complete hour worth of data. To the script which deals with compressing the data, I added the ability to also transfer this data to a server. However, whenever a problem occurs during these scripts (e.g. files that are missing), they stop working. Therefore I also wrote a 'master script' that overlooks both scripts to make sure they are running. Any problems that the individual scripts run into are being reported and documented. The overall lay-out of the master script can be given as

- execute all scripts
- make sure the scripts are always running
- report any problems via e-mail
- document the status and the problems of the scripts in a log file (*.txt)

To save additional hard disk space, I also wrote a script that deletes old result files (*.png) that are being created during the evaluation. This script is also being monitored by the master script. The result of this work is an up and running system that gives “real time” information on the vibrations of the PETRA III experimental floor.

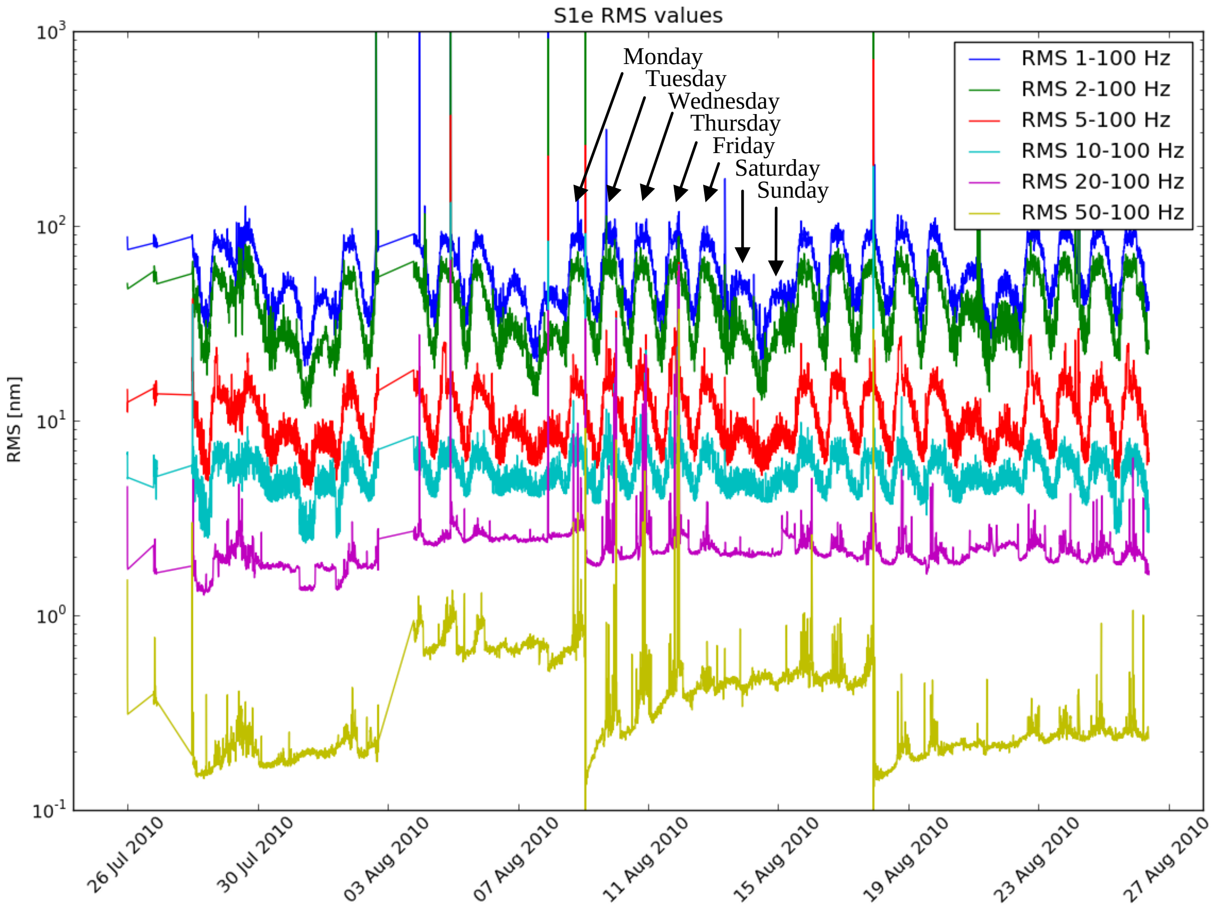

Figure 2-1 *RMS plot of the displacement perpendicular to the beam over a period of one month, calculated from the seismometer signal. The different plots correspond to the different integration limits for the RMS value (see legend). Each point in the curves corresponds to a 5 minute average.*

Figure 2-1 shows the 5 minute average RMS values for the displacement calculated from the seismometer signal during one month. On this figure you can clearly see the day – night cycle (indicated by the arrows), which is most likely caused by cultural noise. Depending on which frequencies are taken into account, different RMS values are obtained. It was however suggested that the experiments at the different beamlines would only be affected by frequencies of 5 Hz and higher (red line). This gives a displacement of the experimental floor between 5 and 30 nm for the directions parallel and perpendicular to the beam. For the displacement according to the height, these values are between 10 and 70 nm. The reason for the big differences in the background, which is more pronounced in the higher frequency range, is still unclear.

2.3. Some minor improvements

During the evaluation of a vibration measurement I noticed that the visual representations of the measured signal and the signals derived from that signal were misleading. This happened when the amount of data points that needed to be plot was too large. The function used for the plotting will only take a certain amount of points when the number exceeds a given maximum, resulting in a wrong plot. The problem is illustrated in Figure 2-2. The three graphs in Figure 2-2(a) are from the evaluation of three consecutive minutes of data. Figure 2-2(b) shows the evaluation of the same data but of the three minutes together. Figure 2-2(c) again shows the evaluation of the same data, but after improving the function.

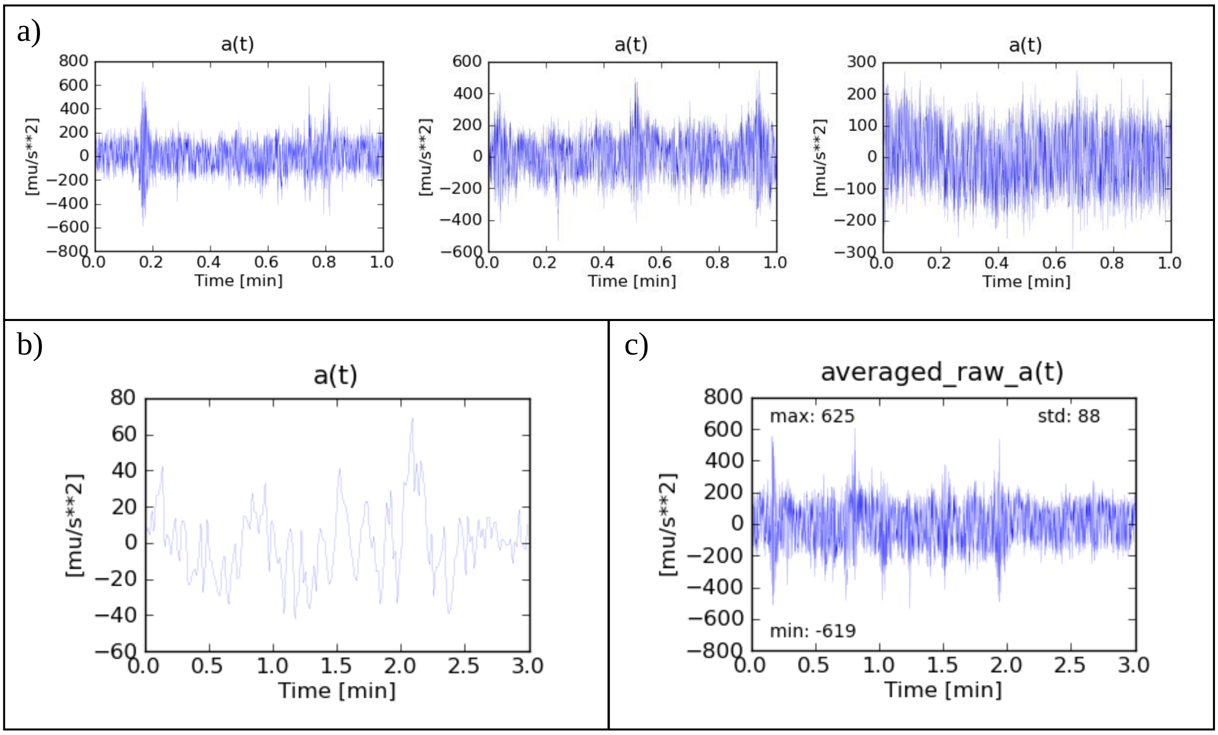

Figure 2-2 *This vibration measurement with an accelerometer illustrates the improvements to the plotting function. (a) Measured signal of three consecutive minutes; (b) Measured signal of the same three minutes, but plotted in the same graph; (c) Same as (b) but with improvements to the plotting function.*

To save time during the evaluation, the function still discards data points when their number exceeds a certain maximum. However, it only discards the smallest amount of points that is needed to get below this maximum. Furthermore, the values of the real minimum and maximum measured by the accelerometers as well as the standard deviation of all the points are shown. This way a more or less correct representation of the measured data is given, even when a large amount of data gets discarded.

3. *Vibration measurements*

For the vibration measurements conducted in this project, two accelerometers were used. One of these accelerometers is used as a reference, which in most cases measures the vibrations of the ground. The second device measures the vibrations of the table/instrument in which we are interested. Lead bricks were placed on top of both accelerometers to assure a good contact with the surface. An example of the result obtained from the evaluation of the signal measured by an accelerometer is given in Appendix I. To discuss the results of the vibration measurements in this report, it is however easier to make use of so-called transfer functions than of the actual signals measured by the accelerometers.

3.1. Transfer functions

A transfer function, as used in this project, gives the ratio of the square root over the power spectral density of the displacement (PSD(s(t))) of two devices for the different frequencies. It doesn’t give any direct information on how much a particular object is vibrating. But in fact, it gives information on how much that particular object is vibrating to a greater or lesser extent than a certain reference object (e.g. the experimental floor). In this project, transfer functions are normally being used to see how much certain frequencies present in the floor get amplified or dampened by a particular table/instrument.

3.2. Comparison of the accelerometer and seismometer signals

To properly use transfer functions, it is necessary for the devices in question to give the same signals when measuring the same vibrations. For this purpose the two accelerometers and the seismometer were positioned close to each other on the floor. It would be safe to assume that each of them underwent the same vibrations. The result of this measurement is shown in Figure 3-1.

It is clear that the transfer functions for both accelerometers are nearly identical. This means that we can safely use both devices (one as a reference, one for the real measurement) for vibration measurements and that we can compare the signals from both devices without introducing some mechanical artifacts. However, the signals from the accelerometers compared to the signal from the seismometer are clearly different (the transfer functions would be constant if the signal from the seismometer would be identical to this of the accelerometers). In all three directions, the seismometer seems to be measuring a lot more displacement for the smaller frequencies up to 1 Hz. In both the x and y direction the same happens for frequencies between 30 and 60 Hz. For the lower frequencies this could be due to the fact that the seismometer is supposed to measure very accurately in that frequency range.

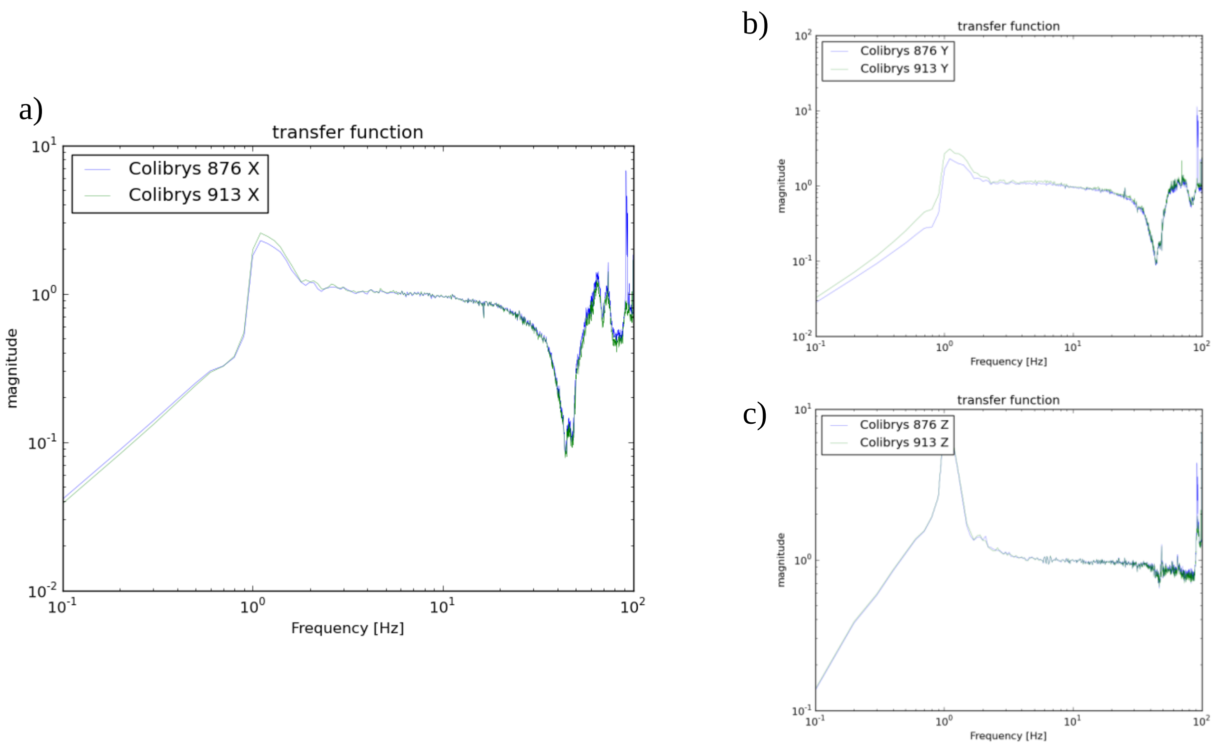

Figure 3-1 *Transfer functions of the two accelerometers with the seismometer as reference. (a) perpendicular to beam; (b) parallel to beam; (c) height. The three devices were positioned very close to each other on the experimental floor.*

The frequency range from 2 – 30 Hz does give a constant transfer function. As said before, the vibration frequencies which would affect experiments at the different beamlines were suggested to be above 5 Hz. Furthermore, high frequencies usually result in very small displacements (as can be seen in Figure 2-1). It can therefore be said that the two accelerometers and the seismometer give the same information, when restricted to the region of interest.

3.3. Comparison of different experimental tables

During my project, I conducted measurements on the experimental tables of beamlines P04, P06 and P11. In all cases one accelerometer was placed on the experimental floor and one on top of the table. The reference was always placed next to a support of the table with the floor.

The transfer functions for the different tables are shown below. As frequencies higher than 100 Hz have very little effect on the displacement, they will not be mentioned when discussing the results.

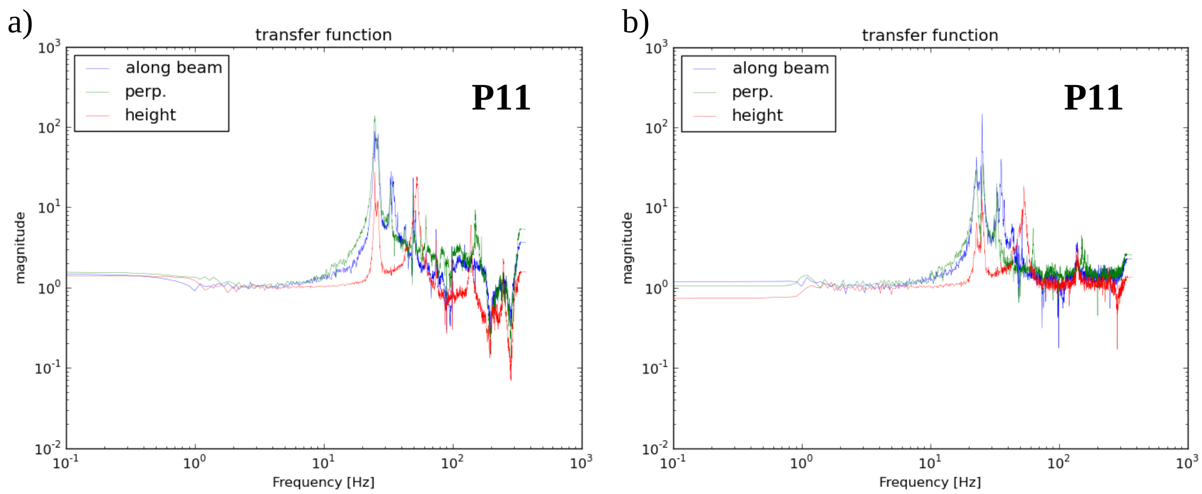

Figure 3-2 *Transfer functions for the long granite table in the experimental hutch of P11. One accelerometer was placed on the floor near the upstream micromover. The other accelerometer was placed on the granite above this micromover. (a) before adjusting the micromover; (b) after adjusting the micromover.*

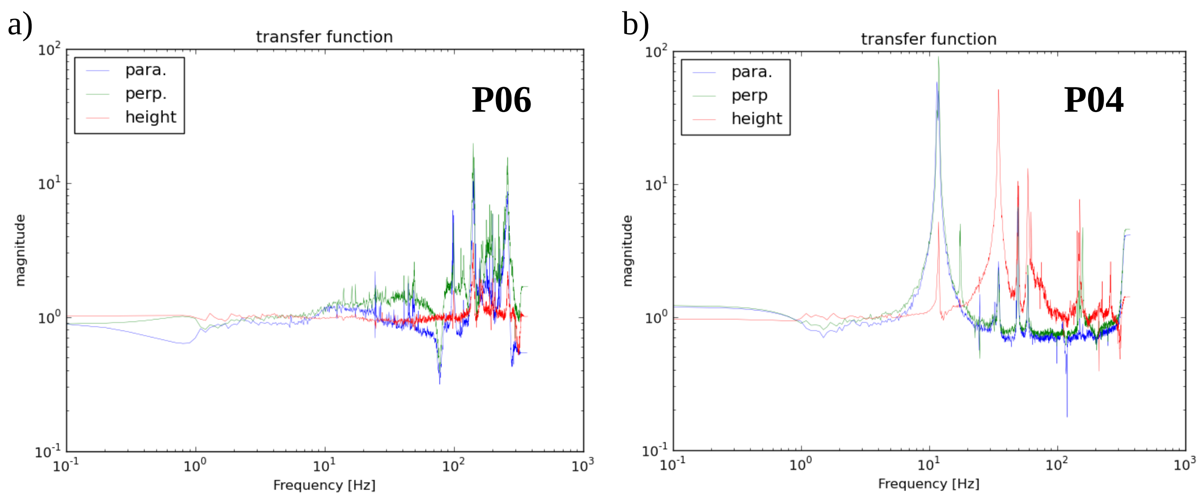

Figure 3-3 *Transfer functions for (a) the granite table in the nanofocus hutch of P06 and (b) one of the granite tables of P04.*

In Figure 3-2(a) we see that the vibrations around 25, 30 and 50 Hz are much more present in the long granite table than in the floor. This effect was much greater at the measurement position shown in Figure 3-2(a) than for the other positions along the length of the granite table. This could have been caused by a bad contact between the table and the upstream micromover. Figure 3-2(b) shows the transfer function for the same measurement position after having moved the micromover up to improve this contact. It is clear that the amplification around 25 Hz has become smaller. For the vibrations around 30 and 50 Hz, the situation has not improved. Figure 3-3(a) shows the result for the granite table in the nanofocus hutch of P06. The signals for both accelerometers correspond very well to each other up to 100 Hz. This means that the granite table seems to be vibrating only as much as the floor itself. For the granite table of P04, it is clear that the experimental table amplifies the frequencies around 10, 30 and 50 Hz (depending on the direction) to a great extend. However, this does not pose a real problem, as this table will be used for experiments with focal spot sizes around 10 μm.

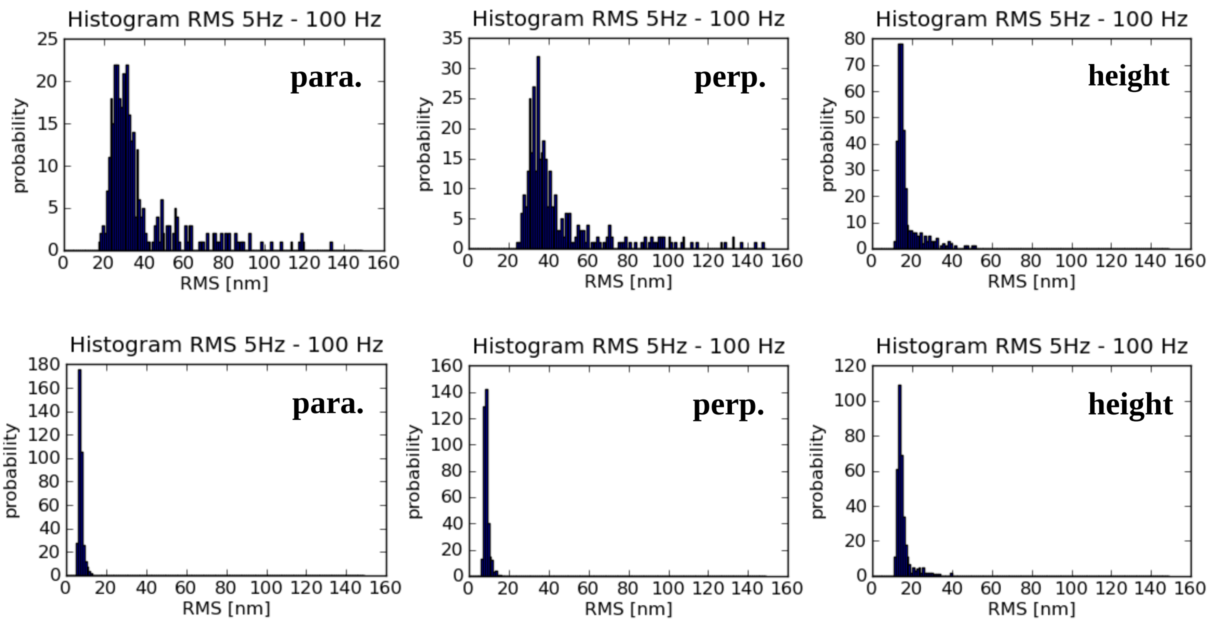

Figure 3-4 *RMS histograms for the displacement of one of the tables of P04 (upper three) and of the granite table in the nanofocus hutch of P06 (lower three). Each value corresponds to a 10 second average and each histogram consists of 360 samples. These measurements were conducted from 3 to 4 am.*

The above transfer functions only give information about the amplification or dampening of certain frequencies. They do not give any information about the amplitude of these vibrations. In order to say something meaningful about the amplitudes with which a table is vibrating, one must find a time to measure a reproducible set of vibrations. To keep things simple measurements were done overnight. We assumed that from 3 to 4 am, the vibrations in the PETRA III experimental hall will show little day to day (or night to night) differences. As the table of P11 was not measured overnight, only the results for P04 and P06 are shown in Figure 3-4. For the table of P06, we see that the root mean square (RMS) amplitude of displacement is ca. 10 nm for both the directions parallel and perpendicular to the beam. For the displacement in height a RMS amplitude between 10 and 20 nm is observed. The distributions for the directions parallel and perpendicular to the beam for the table of P04 are much broader and are shifted to higher maxima (between 30 – 40 nm) compared to the respective distributions for P06. The RMS values along the height look nearly similar in both cases.

3.4. Bridge over the experimental floor in the PETRA III hall

As a final part of this work report the effect of the newly opened bridge on the vibrations of the experimental floor will be discussed. This bridge connects the office floor of the PETRA III hall with the skyway to building 25f. To limit vibrations on the experimental floor, induced by the bridge when people are walking over it, the bridge is decoupled from the experimental floor. The bridge will only be supported by the columns on the experimental floor when it carries a mass of 1 ton or greater. The experimental hutch (EH1) of beamline P01 is situated directly underneath this bridge. A vibration measurement was conducted with one accelerometer close to the granite table inside this experimental hutch. The other accelerometer was positioned between the supporting pillars of the bridge, which are outside the control hutch of P01. Figure 3-5 shows the result of this measurement while two persons were jumping on the bridge. During this measurement, the bridge made no contact with the supporting pillars.

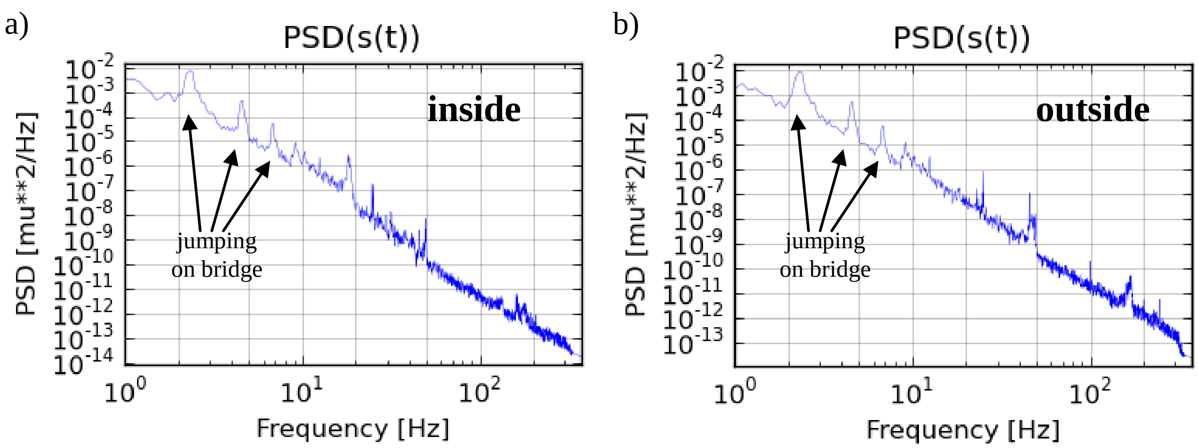

Figure 3-5 *Power spectral density functions of the displacement measured while two persons were jumping on the bridge. These signals are measured perpendicular to the beam direction. (a) signal inside the experimental hutch (EH1) of P01; (b) signal between the pillars outside of the control hutch of P01. The frequencies indicated by the arrows are caused by vibrations of the bridge.*

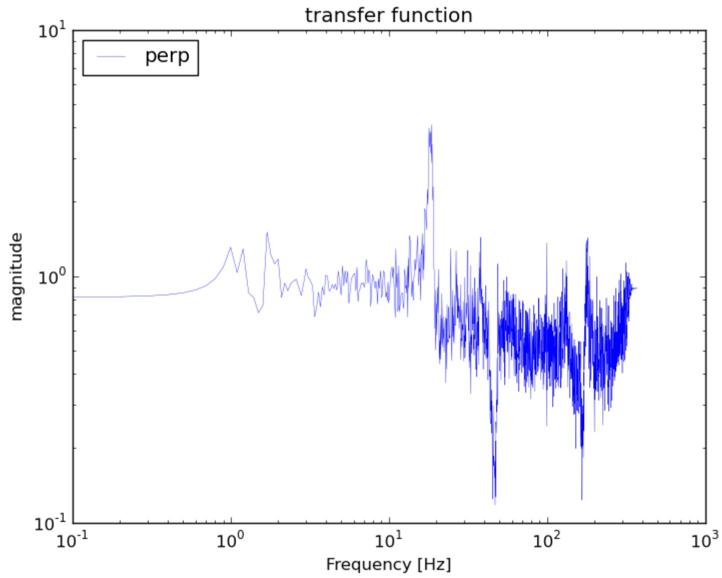

Figure 3-6 *Transfer function of the vibrations perpendicular to the beam direction, measured while two persons were jumping on the bridge. One accelerometer was positioned inside the experimental hutch (EH1) of P01 and one was placed between the supporting pillars outside of the control hutch of P01. The accelerometer outside the hutch was used as reference.*

The three excited frequencies (2 - 3 Hz, 4 - 5 Hz and 6 - 7 Hz, indicated by the arrows) in Figure 3-5 are caused by the two persons jumping on the bridge. It is clear that all three frequencies are present both outside as well as inside the hutch. The same frequencies were also present in the height direction, but were absent in the direction parallel to the beam. In the transfer function, see Figure 3-6, it can be seen that these three frequencies moved almost unhindered from outside to inside the hutch. In this measurement, one can also see that there is a frequency around 20 Hz that is present inside the hutch, but not outside the hutch. In fact, this frequency was also present in the direction parallel to the beam. The cause of this vibration is still unknown. To find out how the vibrations are being transferred from the bridge to the experimental floor, a vibration measurement was conducted to investigate the decoupling of the floor with the supporting bridge structure. One accelerometer was placed on the walkway at ground level between the supporting pillars of the bridge. The other accelerometer was placed about 50 cm away onto the experimental floor. The result of this measurement for the direction perpendicular to the beam is shown in Figure 3-7. During this measurement only one person was jumping on the bridge. In Figure 3-7(a) it can be seen that jumping on the bridge causes vibrations with frequencies around 2 – 3 Hz and 6 – 7 Hz. The vibration at 2 – 3 Hz can be seen in both power spectral densities with nearly the same intensity. However, the vibrations at 6 – 7 Hz do not appear to be transferred from the walkway to the experimental floor. Most of the frequencies above 20 Hz also do not appear to be present in the experimental floor.

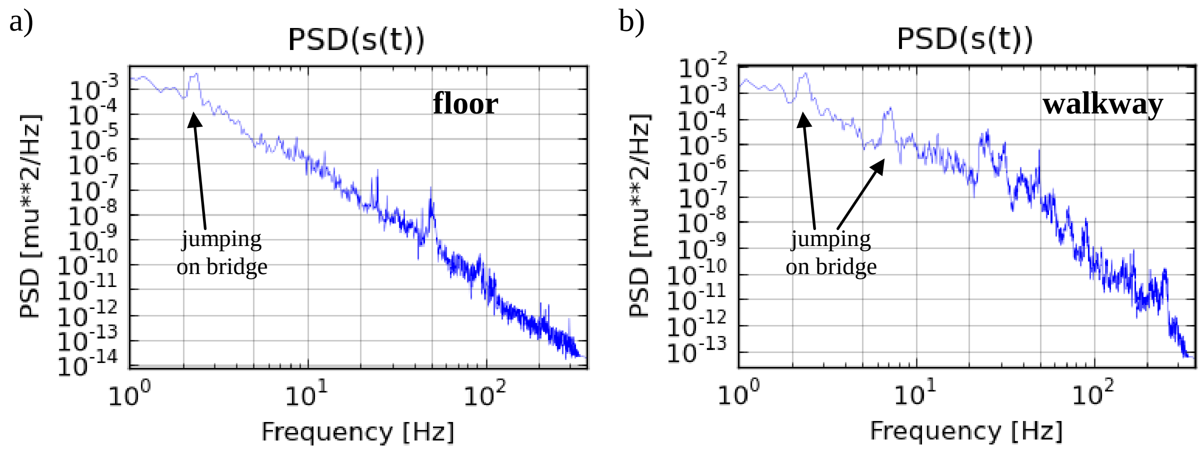

Figure 3-7 *Power spectral density functions of the displacement measured while one person was jumping on the bridge. These signals are measured perpendicular to the beam direction. (a) on the experimental floor; (b) on the walkway at ground level between the supporting pillars of the bridge. The frequencies indicated by the arrows are caused by vibrations of the bridge.*

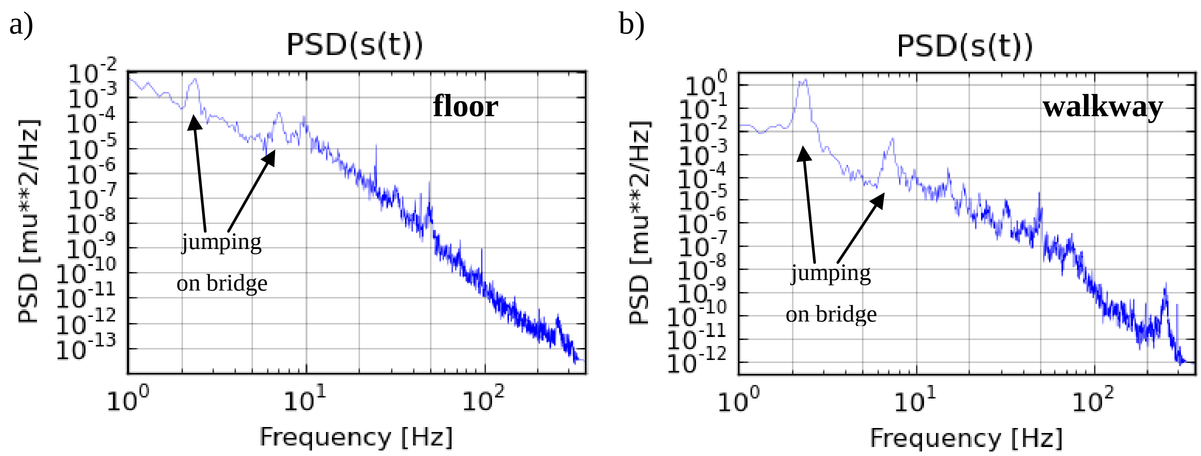

Figure 3-8 *Power spectral density functions of the displacement measured while one person was jumping on the bridge. These signals are measured in the height direction. (a) on the experimental floor; (b) on the walkway at ground level between the supporting pillars of the bridge. The frequencies indicated by the arrows are caused by vibrations of the bridge.*

If we take a look at the vibrations in the height direction, see Figure 3-8, then the same frequencies are again clearly visible. However, this time both frequencies measured on the floor have PSD values which are between one and two orders of magnitude lower than these measured on the walkway. This can also be seen in the transfer function, Figure 3-9. Again, most of the higher frequencies are not present in the experimental floor. In the direction parallel to the beam, there were no frequencies present which were due to the vibrations of the bridge. Similar to the other directions, the higher frequencies were again not present in the experimental floor.

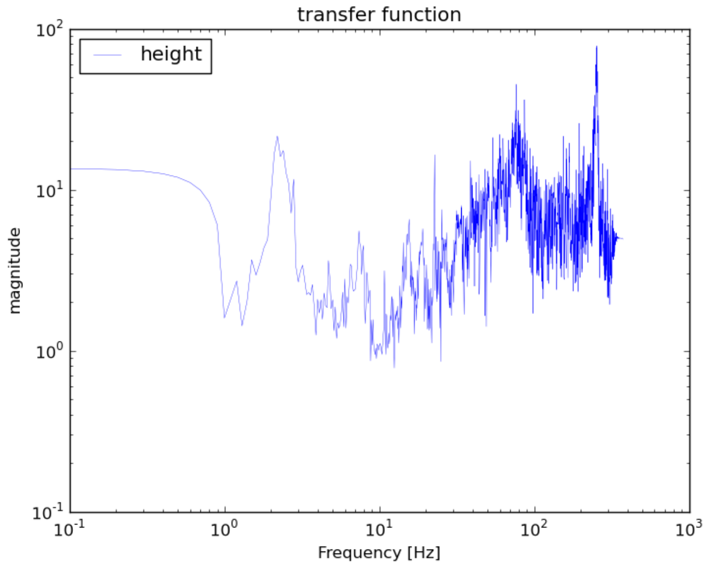

Figure 3-9 *Transfer function of the vibrations along the height direction, measured while one person was jumping on the bridge. One accelerometer was positioned on the experimental floor and one was placed on the walkway at ground level between the supporting pillars of the bridge. The accelerometer on the experimental floor was used as the reference.*

It can be said that the decoupling of the walkway with the experimental floor seemed to have worked. There is however one frequency (between 2 – 3 Hz) in the direction perpendicular to the beam that seems to be able to transfer between the walkway and the experimental floor. It is however unclear that this causes the vibrations measured inside the experimental hutch and outside of the control hutch of beamline P01, as the frequencies above 3 Hz, which are caused by the vibrations of the bridge, are also present.

4. References

1. Franz, H.; Hänisch, L.; Heuer, R.; Spengler, J.; *Hasylab Annual Report 2007 Part I*, **2007**, 147
2. http://www.python.org/
3. http://www.sthurlow.com/python/
4. Pilgrim, M.; *Dive into Python*, APress, **2004**

Appendix I *Example: Result of the evaluation of vibration data*

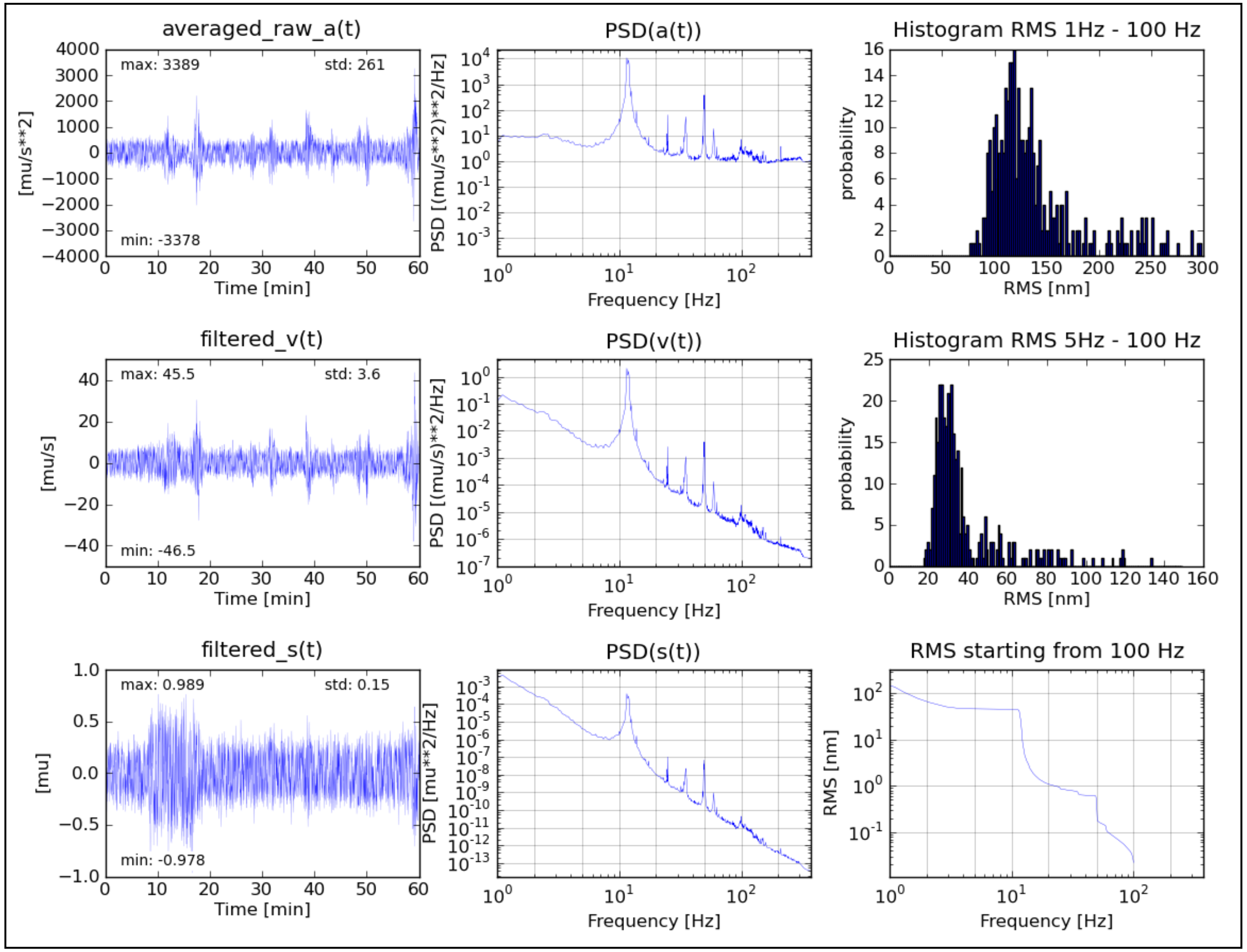

Figure I *Result of the evaluation of data (one hour) measured parallel to the beam by an accelerometer from 3 to 4 am on Monday 31 August 2010. The accelerometer was placed on one of the experimental tables of P04.*