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TECHNICAL REPORT

European XFEL Vibration Report

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1 Introduction

The aim of this project is to study the vibrations inside the Experimental Hall on the European X-Ray Free Electron Laser (XFEL) facilities. More precisely, I measured them on different positions around the hall to determine how frequencies distribute. With these position-dependent study I aimed to find which are the sources of vibration emission, characterize the frequencies that they emitted predominantly and to study how do these frequencies transmit to the experiment. This information can be used by experimentalists to minimize the vibrations that get to their devices, detectors and samples, which are very sensitive to vibration.

1.1 Experimental hall area

The European XFEL houses several instruments which are situated along the beam lines at the end of the three photon tunnels, as seen in figure 1.1.

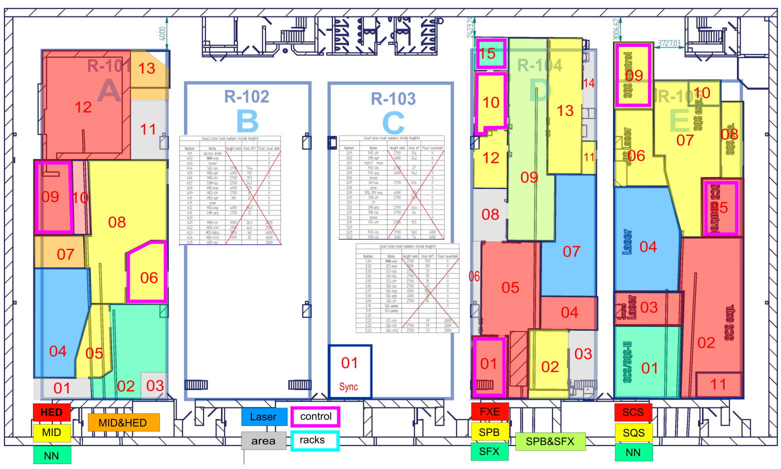


Figure 1.1: Plan of the rooms inside the experimental hall lower level.

1.2 Software and devices

The XFEL facility uses different devices to analyse vibrations on the floor. The ones I used in my project can be classified in two types: seismometers and geophones. On one hand, XFEL seismometers are built by the company Guralp, which also provides us with the software necessary to control them via PC, a program called Scream![1].

[1] Scream stands for Seismometer Configuration, REal-time Acquisition and Monitoring.

These seismometers include three sensors in perpendicular directions, one vertical (z) and two horizontal (N-S and E-W). In our case, we oriented them so that the north arrow of the device points to the right in figure 1.1, perpendicular to the tunnels direction. The main advantage of seismometers is that they can be moved to the locations we are interested in. Therefore, we can do lots of measurements in different spots around whichever room we need and, thus, identify vibration sources, where a frequency of interest should get specially intense.

The raw data we got from *my* seismometer were processed using a Python program written by Gerd Wellenreuther, who is also working at XFEL. I updated this program so that it works in the actual Python3 version, and it outputs 3x3 plots with interesting data about the frequencies distribution in the data measured. I will extend myself on it in section 1.3. We also used another seismometer, which we connected to the XFEL network so that its measurements were recorded and stored online. To access its data, we used a program from Mark Lomperski, Vibration Client. Its position remained more constant, but we also moved it during the summer depending on our interests.

On the other hand, XFEL uses geophones. These are glued to the floor for a firm mechanical contact, and they also have three sensors in perpendicular directions. We used two geophones, located at the pillar between D12 and D10 rooms (MP2-SPB) and in room A12 (MP1-HED) in map 1.1. Both of them are supervised by the company Baudynamics Heiland & Mistler, who processes their data and provides us with daily reports, in the form of some pdf figures and some ASCII txt file containing the RMS function (see more in 1.3) values of that day. To analyse this data, I wrote my own program in Python3 with a set of functions which study the evolution of frequency peaks and plot different figures mostly oriented to quickly analyse the evolution of frequency intensity. As these RMS reports are calculated within one-hour averages, one can see variations along a day, or along different days.

1.3 Data

Both geophones and seismometers measure vibration velocities of the surface below. To analyse the frequency distribution of this raw data, we can Fourier-transform it. Then, if we discard its phases and square its amplitudes, we obtain the Power Spectral Density (PSD) of the vibration, which we can see in figure 1.2. As it comes from a velocity measurement, it shall be a PSD(v(t)). By a product in the Fourier space, we can turn it into a PSD(s(t)), being s(t) the displacement in time, not the velocity. This PSDs represent the power (energy) of the signal as a function of the frequency, so it allows us to study quickly which frequencies are more energetic.

The RMS is the Root Mean Square value of the displacement, which can be obtained from the integral of the PSD(s(t)) in an interval between two frequencies, usually around 1 Hz and 100 Hz. If the interval varies as x Hz to 100 Hz, the result is a monotonically decreasing function where frequencies with high intensities show a steeper (negative) slope, because they had a big contribution to the integral and this contribution is gone as soon as the frequency interval doesn't include them. For example, in figure 1.3 we can see intense steps in 25 Hz and 49 Hz. It must be remarked that the RMS doesn't show the power of frequencies, but its mean displacement (and thus, the amplitude of the vibration).

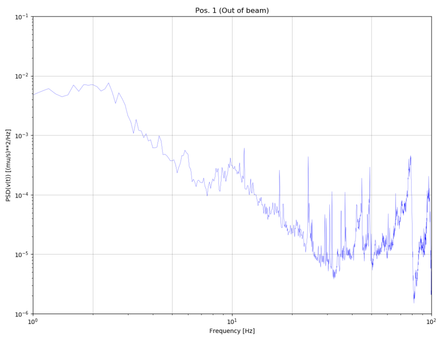


Figure 1.2: PSD(v(t)) function

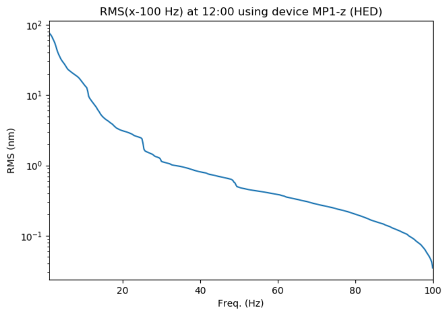


Figure 1.3: RMS(x-100 Hz) function

Usually, PSDs show a huge number of peaks around the interval from 30 to 90 Hz, most of them with high energy. However, when looking to the corresponding RMS, most of these peaks can't be seen. The reason is that a high frequency vibration needs much more energy to vibrate with the same amplitude than a low frequency one. The magnitude we want to minimize for the experiment is the amplitude, not the energy: we don't want our sample to be displaced from the beam line. That's why we must concentrate our efforts mostly in low frequency vibrations and in RMS plots rather than the PSDs (even though both contain useful information).

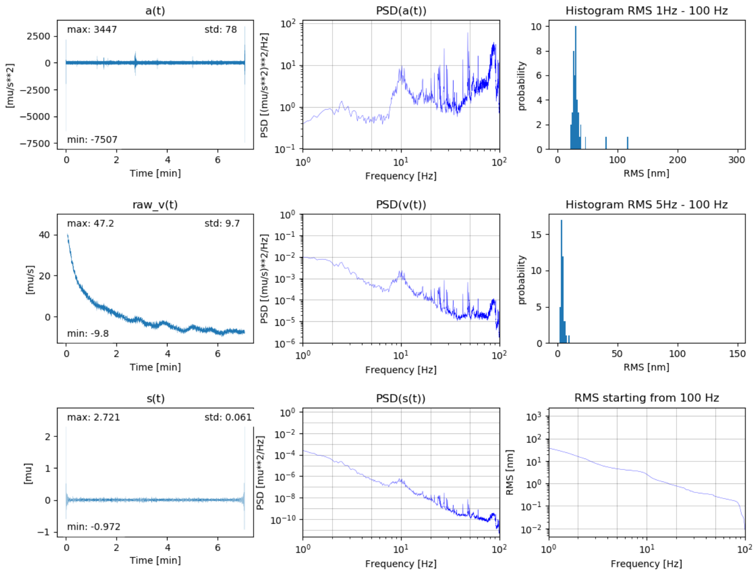


Figure 1.4: Example of an output which can be obtained from Gerd Wellenreuther's program.

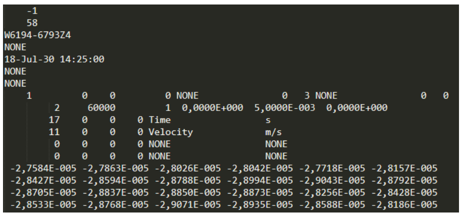
Furthermore, this RMS plot only shows frequencies between 1 Hz and 100 Hz. However, lower frequency RMS are also calculated. There should be some physical reasoning when deciding where to put the lower limit of this plot. Frequencies around 1 Hz have a characteristic length of a few meters, which implies that, in case of displacement, the whole experiment would be displaced simultaneously and the detector would not appreciate differences on the sample position. So, usually the lower bound of frequencies which can produce effective displacements is chosen between 5 and 10 Hz. The corresponding RMS values of the order of 1nm and below are ideal, but up to the order 10nm or 100nm won't interfere too much in microscale measurements.

The plots represented in Gerd Wellenreuther's Python program also show other information, which can be seen in figure 1.4. Besides the signals, the PDSs and the RMS, one can see two histograms, which are useful to detect occurrences that deviate from the averaged intensity. As the RMS plotted is an average of the whole measurement, it can't show whether there were vibrations with higher or lower intensity, or whether all were approximately around the average intensity. The histogram shows the RMS calculated to shorter time periods and plots its intensity. If the histogram is narrow, vibration had more or less the same intensity during all time, which means that the position where the seismometer is placed is quite stable. If there are lots of occurrences with higher RMS intensity, there might be some source of non-continuous vibrations around the position.

1.4 Troubleshooting with seismometer

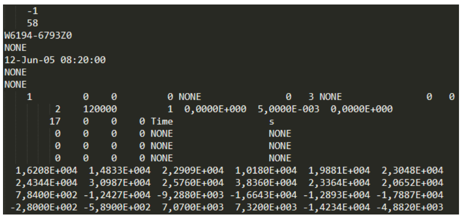
1.4.1 Wrong data recording

After getting our hands on the seismometer, we tried to do some measurements in the SPB Optics Hutch. However, after trying to process the data with Wellenreuther's program, we found all PSDs to be blank, and RMS with a magnitude around 10^{-8}nm, which would mean that the seismometer can register vibrations at the quark scale. As that is beyond reality, we took a look at the UFA data that Scream was exporting, that showed a header and some data like those of figure 1.5. We compared this same file to the ones that we could access from the records of Wellenreuther in the past (such as figure 1.6). From this comparison we can determine two main differences: there's an extra row in the bad file `11 0 0 0 Velocity m/s`, and the bad data are 11 orders of magnitude below good data. One might say that the former is the cause, while the latter is the consequence.



```
    -1
    58
W6194-6793Z4
NONE
18-Jul-30 14:25:00
NONE
NONE
    1         0    0         0 NONE                 0   3 NONE              0   0
        2     60000          1  0,0000E+000  5,0000E-003  0,0000E+000
       17     0    0    0 Time                  s
       11     0    0    0 Velocity              m/s
        0     0    0    0 NONE                  NONE
        0     0    0    0 NONE                  NONE
 -2,7584E-005 -2,7863E-005 -2,8026E-005 -2,8042E-005 -2,7718E-005 -2,8157E-005
 -2,8427E-005 -2,8594E-005 -2,8788E-005 -2,8994E-005 -2,9043E-005 -2,8792E-005
 -2,8705E-005 -2,8837E-005 -2,8850E-005 -2,8873E-005 -2,8256E-005 -2,8428E-005
 -2,8533E-005 -2,8768E-005 -2,9071E-005 -2,8935E-005 -2,8588E-005 -2,8186E-005
```

Figure 1.5: Bad data and header exported by Scream from our seismometer.



```
    -1
    58
W6194-6793Z0
NONE
12-Jun-05 08:20:00
NONE
NONE
    1         0    0         0 NONE                 0   3 NONE              0   0
        2    120000          1  0,0000E+000  5,0000E-003  0,0000E+000
       17     0    0    0 Time                  s
        0     0    0    0 NONE                  NONE
        0     0    0    0 NONE                  NONE
        0     0    0    0 NONE                  NONE
  1,6208E+004  1,4833E+004  2,2909E+004  1,0180E+004  1,9881E+004  2,3048E+004
  2,4344E+004  3,0987E+004  2,5760E+004  3,8360E+004  2,3364E+004  2,0652E+004
  7,8400E+002 -1,2427E+004 -9,2880E+003 -1,6643E+004 -1,2893E+004 -1,7887E+004
 -2,8000E+002 -5,8900E+002  7,0700E+003  7,3200E+003 -1,4234E+004 -4,8820E+003
```

Figure 1.6: Header and data exported by Scream from Wellenreuther.

We did not find any solution to this issue. We tried using Wellenreuther's laptop instead of Sabine Cunis' one, which seemed to solve the issue. Its cause might be the incompatibility of the seismometer or Scream software with some laptops such as Cunis' personal one.

1.4.2 North-south direction masses stuck

After a week of correct measurements, some data measured by the seismometer in the north direction began to appear constant. The values that it collected were always around `7,1537E+006`, and indeed the real time view showed a flat signal in this sensor, while the others kept working well. Also, every 10 minutes, an intensity plateau appears during 1 minute. The issue came approximately after doing some measurements over a sloped surface. Even though that might not be the cause, it is recommended to watch out for the leveling bubble in top of the seismometer and correct the slope with its adjustable feet to prevent issues like this.

At first sight, it seemed that the seismometer had trouble centring the N-sensor mass: the plateaus represented this unsuccessful attempts to do so (because an auto-centering every 10 minutes option was enabled in the settings). In order to solve this issue, we tried to repeat the lock/unlock/centre procedures several times while having the seismometer on a slope, as suggested by Mark Lomperski. However, that didn't solve the problem, the seismometer couldn't put the mass in place. After contacting with Guralp Systems, they asked us to take a look at the mass position sensors (which record the position offset of each mass): M8 (corresponds to z mass), M9 (NS) and MA (EW)[2]. The expected values of their output should be *small* (around 6 digits), and the text in Scream main screen should be black (red text means the mass is not centred). So, the M9 sensor showed a constant high number and a red text. That meant the sensor was faulty and needed repairing, as Guralp Technical Service stated.

However, as Guralp's repairing service is very slow and measurements still could and needed to be made, we kept the device. In order to measure vibrations in the north direction, we just had to rotate the seismometer 90 degrees, so that the east sensor was oriented to the north direction. That made measurements twice as long, but possible.

[2] If not activated by default, one can activate these sensors by right clicking the device name in Scream main screen, then going to `Configure > Mux Channels`.

2 Seismometer data analysis

As I said before, my methodology while working with the seismometer was to locate it on different positions around the floor. At the start, my aim was to find sources of vibrations by analysing where did some frequencies intensify and, afterwards, looking for vibrating devices in its surroundings. To do that, I needed a great amount of measurements around all the experimental hall, and so I made: all the measurements I have done can be seen in figure 2.1.

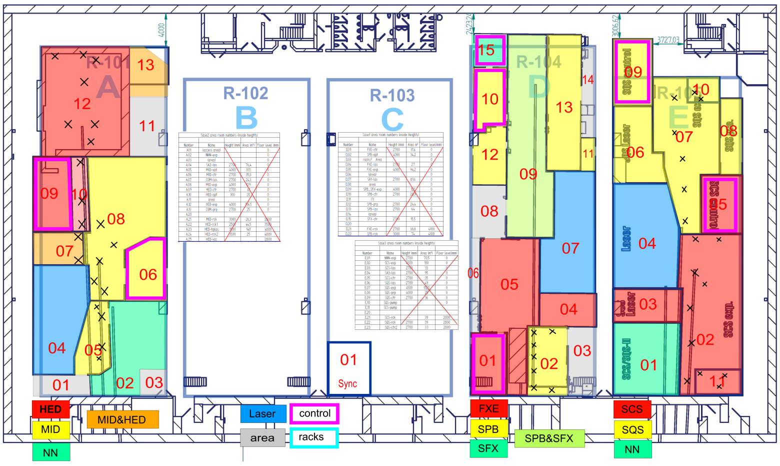


Figure 2.1: Positions of all the measurements I have done with the seismometer. They are mostly located along the beam line pipes, where the equipment and experiments are placed.

After these measurements, I used Wellenreuther's program and compared the data while keeping in mind the different positions. That's the main difference with the geophone data analysis: while geophone data only give time-dependent variability, the seismometer can offer position-dependent information.

My study was focused on three distinct objectives: knowing which were the sources of vibration, how did the emitted vibrations travel to the experimental devices, and which was the impact of the vibration on the instrument.

2.1 Vibration sources

My measurements started inside the SPB Optics Hutch because it was very accessible at that moment. A characteristic output of the data obtained there can be seen in figure 2.2. The first thing we should look at is the RMS function plot. There we

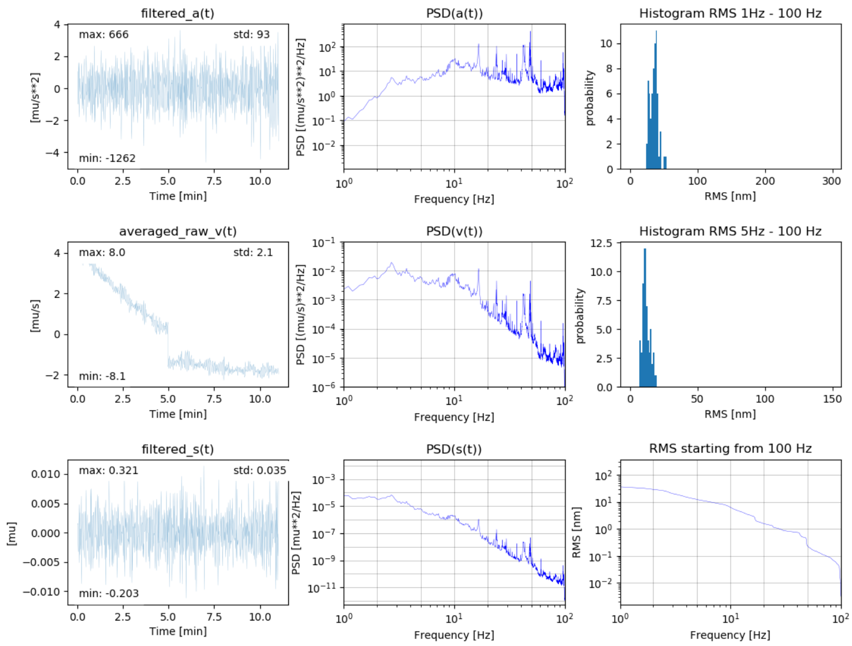


Figure 2.2: Vertical vibrations data from the SPB Optics hutch.

can see that RMS(1-100 Hz)=25 nm, and RMS(5-100 Hz)=11 nm, which are correct values. SPB Experiment is already open to users, and until now no complaints have been addressed to the PSPO group about vibrations messing up experiments. So, we may take this RMS values as a reference for the future.

The RMS function decreases smoothly most of the time, except in two frequencies: 16 Hz and 49 Hz. There we can see two small steps which mean that those two frequencies contribute noticeably to the average displacement: 16 Hz contributes with 1nm and 49 Hz with 0.4nm. Even though this input to total displacement is very low, one still should try to locate the origin of these frequencies.

2.1.1 49 Hz frequency

It is already known to some scientists and engineers around XFEL who have worked in vibrational measurements that 49 Hz is a common frequency which can't be avoided anywhere around the experimental hall. This statement can be also checked in the geophone data measurements, where a 49Hz peak is seen in both HED and SPB locations. According to Idoia Freijó-Martín and Gerd Wellenreuther, 49 Hz frequency is usually related to the power supply of XFEL facility (which has a characteristic frequency of 50Hz) and, therefore, to noise generated by electronic devices. However, when looking in detail to the power company recordings shown in figure 2.3, this frequency is predominantly slightly below 50 Hz, but never goes further than 49.96 Hz.

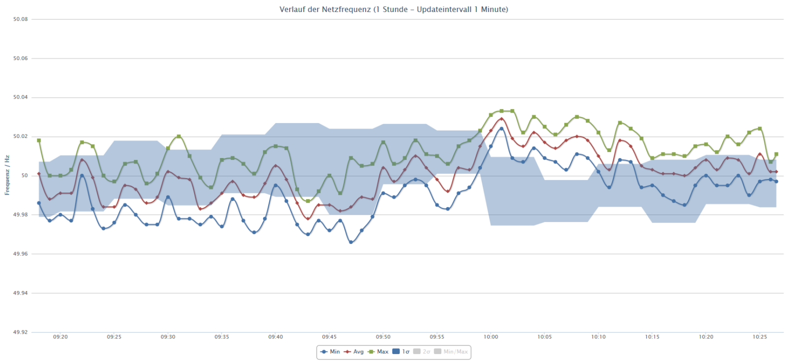


Figure 2.3: Variation of the frequency of electric power supplied to XFEL between 09:20 and 10:20. It can be seen that mostly the frequency is below 50 Hz, but only slightly: around 0.02 Hz less.

After comparing the data of the seismometer (using Mark Lomperski's program) and the power supply on the same time interval, trying to look for simultaneous behaviours, the results show no correlation between the two evolutions. Furthermore, the seismometer frequency peaks are always around 49.0 Hz, which is distant from the 49.98 Hz of the power supply. However, one still can't discard this cause-effect relation, because some damping might occur which decreases the vibration frequency in comparison with the power supply one.

Anyway, it is still of interest getting to know where does this vibration comes from. Thanks to Sabine Cunis, who suggested that the source of this frequency was inside the FXE Racks room (FXE-rck) -which is just next to SPB-opt roof-, the source of the vibrations found in SPB-opt could be located very easily. Indeed, inside of that room the intensity of 49Hz vibration increased strongly. For example, in the room's corner which is most in contact with the SPB-opt roof the RMS intensity of this frequency goes up to 20 nm, as can be seen in figure 2.4.

The 49Hz peak is remarkable everywhere inside the room, but it gets more intense the nearer it gets to a chiller, arriving to a RMS displacement of around 350 nm next to the chiller. Vibrations are more intense in horizontal directions, where they can get up to 900 nm displacement. Both results imply that the corresponding measurements surfaces are vibrating intensely, and that can be sensed just by touching the chiller, or even the racks.

So, one might conclude that the source of the 49Hz vibration measured inside SPB-opt is just inside FXE-rck, and may come both from the chiller and the

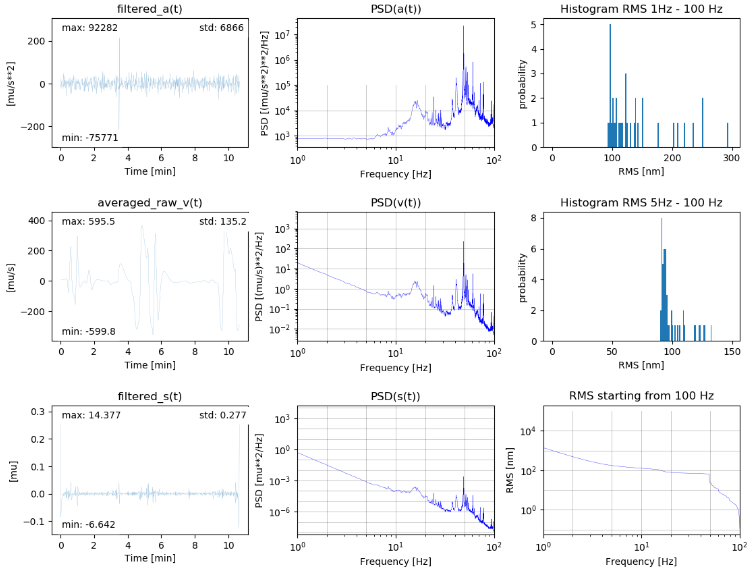


Figure 2.4: Measurement in the E-W direction inside FXE-rck in the corner nearest to the SPB-opt roof. Data is not very good, but still show a huge intensity around 49Hz.

electronics working inside the racks, as one could feel both of their surfaces vibrating noticeably.

2.1.2 16 Hz frequency

The other frequency which we have detected intensely in SPB-opt was the one of 16 Hz. However, this frequency can only be detected in the vertical and in the E-W direction, that is, almost parallel to the beam lines and the photon tunnels. This exact same behaviour happens all around the experimental hall: there's no 16Hz vibration in the N-S direction. This results can also be seen in the geophone data which will be discussed in the next chapter.

Even though this behaviour offers an interesting clue towards finding the source of this frequency, we have arrived to no conclusion. According to Sabine Cunis work, this frequency has had an evolution in time. In other words, it has not appeared during all the time while vibration measurements have been being done, which makes its study more suitable to a time-dependent analysis rather than a position-dependent one. That's the reason why I won't focus more on this frequency during the rest of the report.

2.1.3 Vacuum pumps emission

Even though we could not see more remarkable frequencies in SPB-opt other than 49Hz and 16Hz, there are still other rooms to investigate. For example, a characteristic result from measuring at the SCS Experiment room (SCS-exp) can be seen in figure 2.5. This RMS shows a noticeable step (of 15 nm) in the 30Hz frequency, and also some other peaks around 49Hz (already known) and 60 Hz. 60 Hz peak can be also measured usually all around the hall, which makes it very interesting to study.

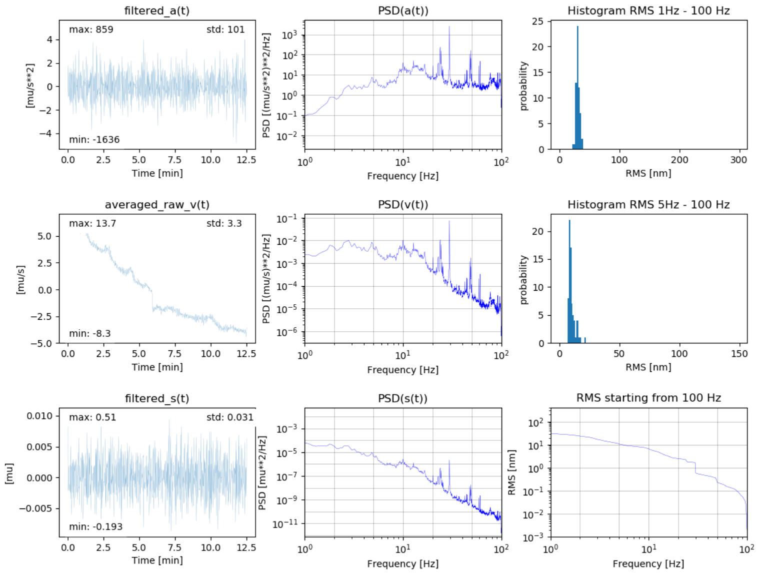


Figure 2.5: Measurement in the vertical direction inside the SCS-exp room.

The SCS-exp room had some vacuum pumps working at the same time as we were doing the measurements with our seismometer and couldn't be switched off for that time being. Some of those pumps, which were located in two different positions along the beam line, are not active when the users come to do their experiments. Thus, it is important to measure their vibration emission, so the team can know which frequencies will get weakened once the pumps are off, and therefore, shouldn't need to worry about.

Thanks to some of the measurements taken around these pumps, the results of which can be found in figure 2.6, we could locate in which frequencies these vacuum pumps emit: all slightly below 30Hz, 60Hz and 90Hz. It should not be a coincidence that they are multiples of each other, as they might correspond to some of the different harmonics in which the pump can oscillate stably. However, we have seen in the rest of positions that only the 30Hz peak has a remarkable impact on the vibrations around

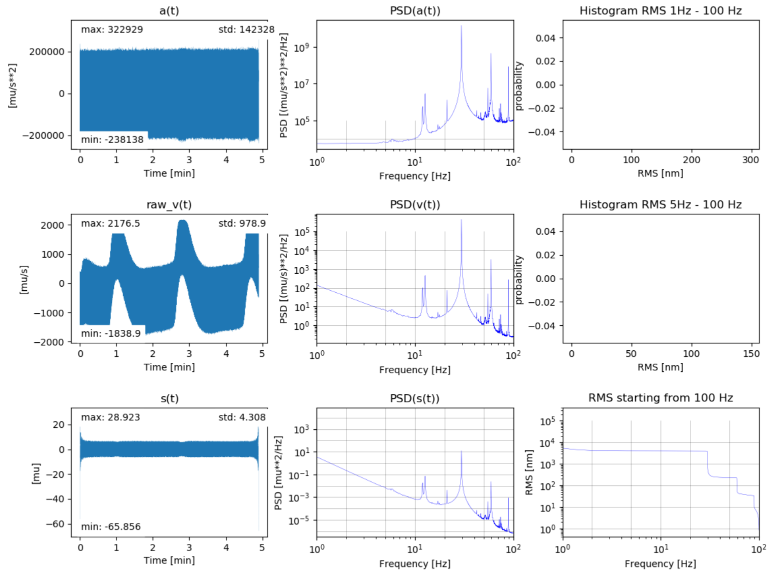


Figure 2.6: Measurement in the horizontal direction with the seismometer *touching* a pump from SCS-exp.

all the area, while 60Hz and 90Hz steps get much more weaker as we move away from the pump. It's not just that the 60Hz and 90Hz peaks have a lower energy (less PSD values), but also we already know that the lower the frequency, the higher the energy needed to produce the same vibrational displacement. Both are the causes why these harmonics can't even be seen when looking at the RMSs.

We can also take a look at the measurements from MID Optics hutch (MID-opt), which were also taken while some vacuum pumps were working. The most prominent frequencies that also appear in those measurements are also 30Hz and 49Hz. If we also take a measurement just next to one of the pumps position, we get an output such as the one from 2.7. In this case, we get almost exactly the same result. In this case the peaks are shifted a little bit to lower frequencies, such as 29Hz, 59Hz and 88Hz. However, this damping won't be considered, and I'll treat both pumps as emitting in the same frequencies.In this case we also see that only the 30Hz vibration gets to really impact on the floor vibration, while 60Hz and 90Hz get weakened and don't even have a distinguishable contribution to the mean displacement.

Finally, we also did measurements of the vibrations emitted by another kind of pump (smaller one) which was located in SQS-exp room. In this case, the emission was mostly focused in the 23 Hz and other near their harmonics: 49 Hz, 72 Hz and 96 Hz, approximately. The 23 Hz frequency resembles a typical frequency which can bee seen usually in the Experimental Hall around 24-25 Hz. In the areas where these

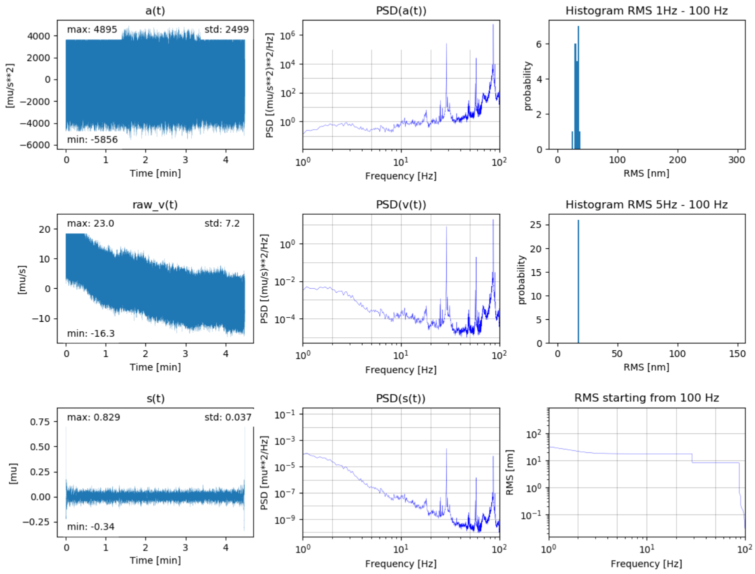


Figure 2.7: Measurement in the horizontal direction with the seismometer *next to* a pump from MID-opt.

frequencies appear, these kind of small pumps might be the culprits.

Also in the SQS-exp there's some kind of Pfeiffer vacuum pumps which emit in a wider ranges of frequencies, but there's only one which transmits remarkably and that gets to impact on the experiment, which is around 92Hz. As it is a high frequency, it isn't as remarkable when looking to the corresponding RMS.

2.1.4 Other frequencies

Other frequencies that have been measured with the seismometer include, most remarkably, 9 Hz, 11 Hz, 40.5 Hz and 53 Hz. However, as my time was limited and its impact was not generalised and/or intense, I didn't take a deep look into them and no overall conclusion arose from their study.

2.2 Vibration transmission

I have already discussed which are the main sources of vibrations around the experiments being carried in XFEL, so now the following question that should be asked is quite clear: how do these vibrations travel from the sources to the experimental devices? If we manage to acknowledge this, we can engineer ways to minimize the vibrations that actually get to the devices when the source can't be switched off. The main media through which vibrations should transmit are the floor, pillars and pipes.

2.2.1 Transmission through the floor

The first thing we have to look up if we want to know if the floor is transmitting too much vibrations is how these get from the source to the floor. In the cases we studied, we placed the seismometer on top of tables where some pumps stood, and then placed it next to the table's legs, for comparison. Most of these tables have spring-like structures which decouple the vibrations from the pumps to the floor, but makes the whole table oscillate much more easily. We could find these kind of tables in the experiments room of both SCS and SQS.

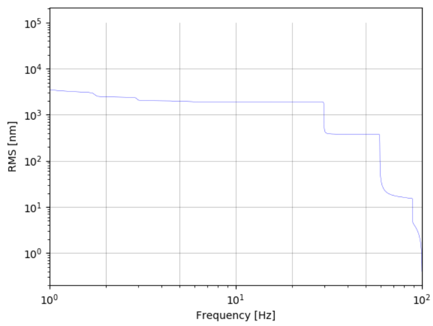


Figure 2.8: z RMS measured on top of the table with pumps in SCS-exp.

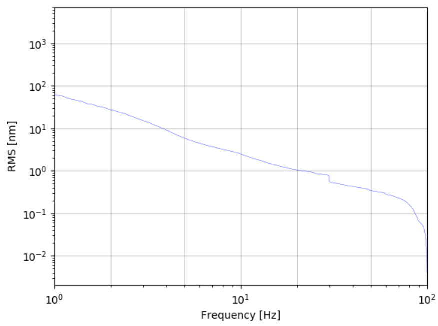


Figure 2.9: z RMS next to a leg of the same table in SCS-exp.

The SCS measurements can be seen in figures 2.8 and 2.9. If we take a look at the RMS(1-100Hz) value we can see that the spring mechanisms in the table weaken the intensity from 2400 nm on top of the pump to 60 nm on the floor. Thus, the vibration seems to be reduced by two orders of magnitude when transmitting to the floor. However, the weakening is even bigger, as the 2400nm is quite pathological (the chillers vibrate much further than the micro-scale) and the real displacement should be at least in the millimetre. The same thing can be said about those specific frequencies which we know pumps emit. 30 Hz contribution to the RMS goes from 600nm to 0.4 nm, and the other two (60 Hz and 90 Hz) aren't even noticeable in the floor measurement.

A similar measurement is the one I did in the SQS-exp room, with the same kind of table. In this case, the frequencies which the pumps emit are not the same (in this case, the pump seems to emit approx. at 92Hz), but the phenomena is the same. We can see the damping in action in figures 2.10 and 2.11.

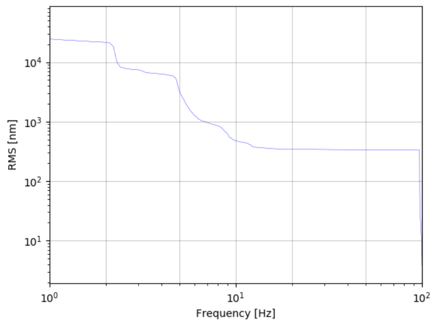


Figure 2.10: z RMS measured on top of the table with pumps in SQS-exp, although there's some strange behaviour at low frequencies.

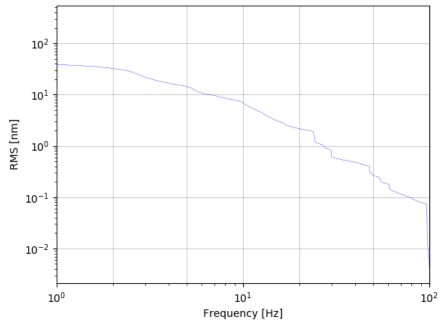


Figure 2.11: z RMS next to the same table in SQS-exp.

Even though the strange behaviour at low frequencies, we can see that the RMS displacement is much more strong on top of the table than on the floor of the pump room. The intensity of the 92Hz peak goes from 180 nm to 0.7 nm. So, again, the decoupling structures are working as expected.

However, how does the transmission work when there is not damping structures? We can take a look at it by measuring next to some pumps from SCS which are working on top of some little wooden trolleys which shouldn't decouple the vibration. In figures 2.12 and 2.13 we can see the comparison between a measurement with the seismometer touching the pump with another one a little bit away from the pump.

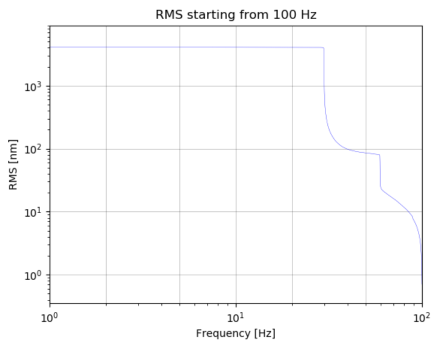


Figure 2.12: z RMS with seismometer touching pump from SCS-exp.

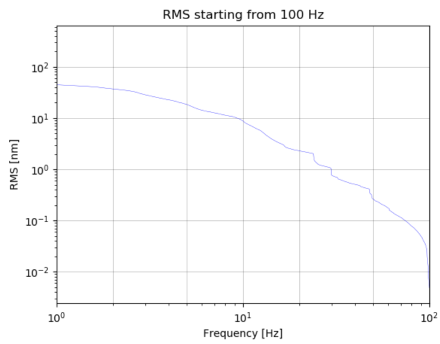


Figure 2.13: z RMS in FFT position in SCS-exp (near the pump).

In this case we can also see that, even in the absence of a damping/decoupling structure, the vibration emitted by the pump doesn't get transmitted almost at all to the floor. As we know from wave propagation theory, when changing of media

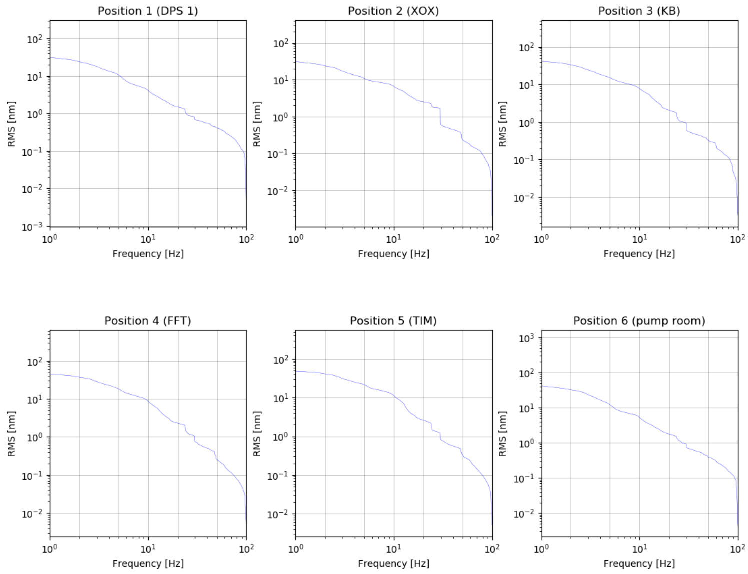


Figure 2.14: Vertical RMSs of different measurements depending on the position inside SCS-exp.

the energy of the incoming wave will split into the reflected wave energy and the transmitted wave energy. When a material wave travels from a less dense media to one which is denser (as it's the case from the pump to the floor), the corresponding transmission coefficient gets smaller the bigger their difference of densities, so only a small fraction of energy gets into the transmitted wave, given the case that the floor density is quite higher. So, even though damping is also useful for decoupling any annoying frequency, vibrations are not really well transmitted to the floor.

However, once they get to the floor, the transmission inside the same media has no noticeable weakening. To see that, we can take a look at the measurements which were made at the different points inside SCS-exp, in figure 2.14. In these RMS we can see that almost everywhere in the room the intensity of the step corresponding to 30Hz doesn't vary much even near those points that are far away from the pump, such as position 5 (TIM). Anyway, the strength of this step is so weak that it can almost be neglected, thanks to the low transmission coefficient.

2.2.2 Transmission through pillars and walls

We also tried to see whether vibrations get transmitted vertically through pillars and walls, but no remarkable outcome has resulted from this study. We compared the vibrations on the SPB-opt hutch and its roof but could not find any common frequency other than 49Hz, which decreases from 5 nm on the roof to 0.4nm on the roof (then, one order of magnitude). Anyway, vibrations are much more intense on the roof than in the hutch, specially in those areas where there's no wall or pillar below, as expected. For example, the RMS(1-100 Hz) also decreases in one order of magnitude (almost two in areas without support under them).

2.2.3 Transmission through pipes

Even though we have seen that the floor is not a worrisome transmitter of the vibrations, we still have to take a look to other kind of media: pipes. Vacuum pumps are connected to the experiment and its devices via pipes, so the vibration could possibly be transmitted through these too. Firstly, we have to remark that most of the pipes are either quite stiff and well fixed to the ground or have some decoupling structures in some fragments of the pipes, so they should be prepared to minimize the vibrations. Despite this, it is not really the case.

We will take a look again at the SCS-exp pumps which work in a closed room and which don't transmit much vibration to the floor. From these pumps there are some pipes which get out of the room and are connected to different devices in the beam line direction. In figures 2.15 and 2.16 we can find the comparison between the vibration measured without touching one of those pipes and when touching it.

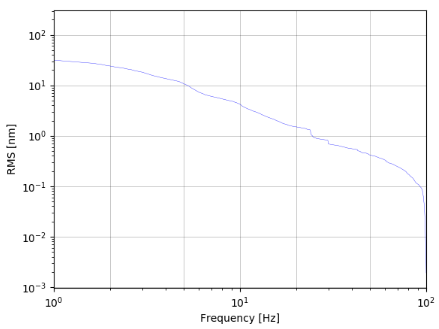


Figure 2.15: z RMS with seismometer touching pipe from SCS-exp.

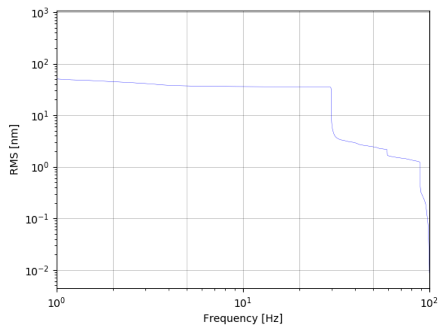


Figure 2.16: z RMS with seismometer not touching pipe in SCS-exp.

As we can see, there is a clear difference in both cases. The 30Hz step becomes much steeper and both this step and the total RMS increases by around 20 nm. It might not be too much for the RMS(1-100Hz) value, but it indeed is for the 30Hz step (which has increased in one order of magnitude) and the RMS(5-100 Hz), which goes from 10 to 30 nm.

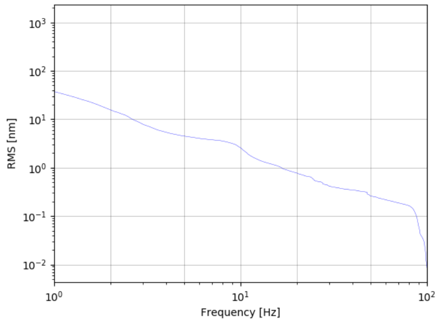


Figure 2.17: z RMS with seismometer touching pipe from SQS-exp.

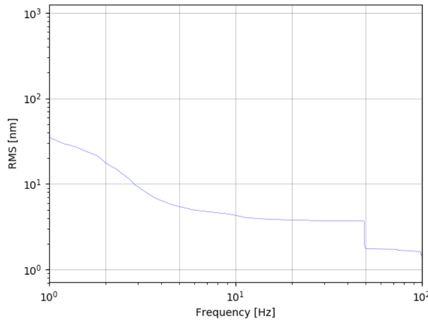


Figure 2.18: z RMS with seismometer not touching pipe in SQS-exp.

The same behaviour can also be seen in the SQS-exp room, the pumps rooms of which also has some pipes which are connected to different parts of the experiment. The comparison can be seen in figures 2.17 and 2.18. In this case, the position of the seismometer is quite far from the pumps room, so now we can see that this kind of transmission can get to wherever the pipe is connected, so it is a phenomenon worth being aware of.

2.2.3.1 Pipe damping structures

To try to minimise the vibrations transmitted through pipes, one can use some anchoring structures to fix the pipe to the floor, similar to the ones that can be seen in figure 2.19, corresponding to SQS-exp. To study how much do this anchors damp vibrations, we made two measurements: one next to the right anchor (before the vibration from the pump room passes through the anchor), and another next to the left one. The corresponding RMS are outputted in figures 2.20 and 2.21. We can

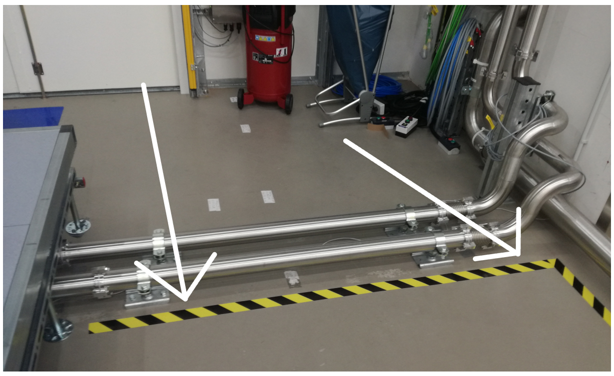


Figure 2.19: Pipe anchors with the seismometer positions pointed out.

see that there is indeed some damping made by these structures, because all the

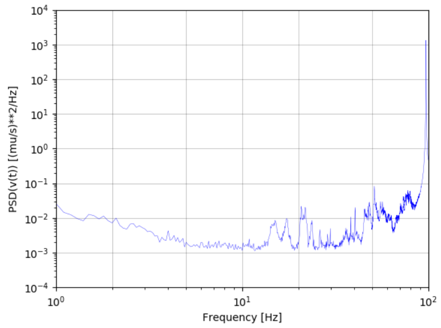


Figure 2.20: E-W PSD measured before the right anchor (less damping).

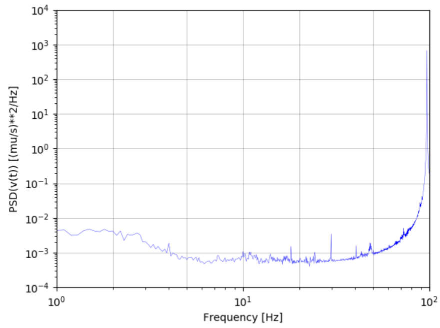


Figure 2.21: E-W PSD measured before the left anchor (more damped).

weak vibrations almost disappear next to the second (left) anchor. However, the most intense frequency, 92 Hz, which is the one emitted by the pump room doesn't disappear. It is indeed weakened, but still has remarkable energy. If we take a look at the corresponding RMS, we see a weakening in its intensity of approximately 20 nm, which is a 20% reduction when compared with the total intensity of the step (100 nm).

2.2.4 Transmission through ventilation ducts

One could also take a look to the ventilation ducts which might also get foreign vibrations inside the rooms where vibration sources want to be avoided. That's the case, for example, in SCS-exp. There, there's a ventilation pipe next to the entrance where one can feel vibrations. It seemed interesting to place the seismometer touching this duct in order to see if it vibrated strongly in any specific frequency, and the result can be seen in figure 2.22. As we can see, there's no characteristic frequency for its vibration, and the RMS is not particularly intense. Even though there is a 40nm contribution to the RMS around 15Hz, this is not a dangerous amplitude and therefore we needn't be worried about it.

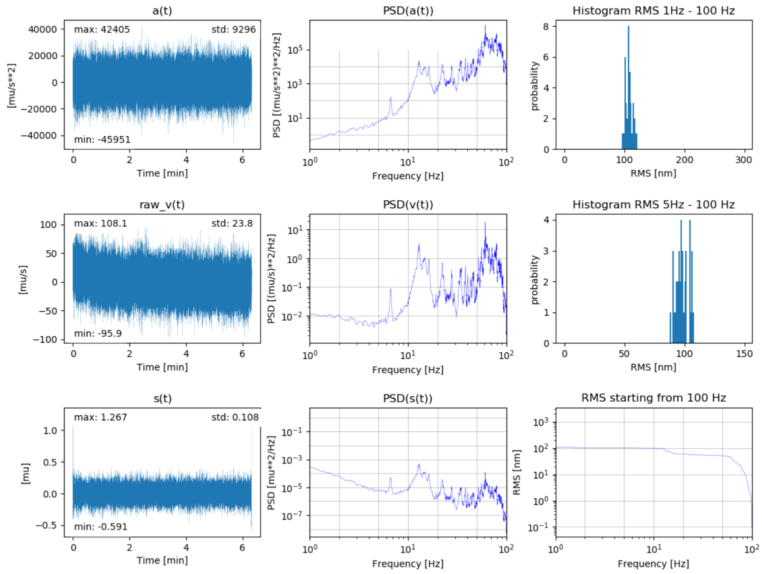


Figure 2.22: Data of the horizontal measurement of the vent pipe in SCS-exp.

2.3 Impact on experiments

Until this point, all the measurements that we have done have been only on the floor, so one might say that we don't really know how vibrations change from the floor to the experiment itself. To address this issue, we also made a few measurements on top of experiments chambers and support tables. In this section we will discuss briefly the results from these measurements.

2.3.1 Damping of vibrations by optical supports

In HED Optics hutch we had the chance to do measurements on top of the supports where optical systems are placed because there was one of these empty, so we took the chance. Some of the corresponding results can be seen in figures 2.23 and 2.24. We can see no huge difference between the measurement on the floor than on the support, which means that there is no noticeable damping, but still the support is being as stiff as the floor. The only remarkable difference is the increase of the 49Hz step when measuring on top, which may come from another source other than the floor.

Also, we repeated the same measurements with a vibrating vacuum cleaner working at the same time, to know how are intense vibrations damped. However, the results

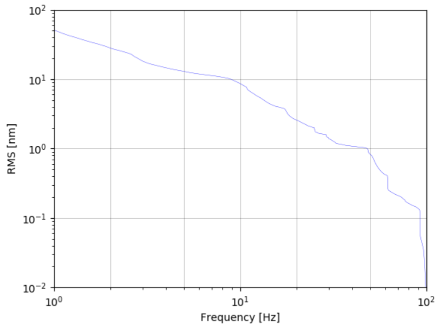


Figure 2.23: z RMS with seismometer below optics support inside HED-opt.

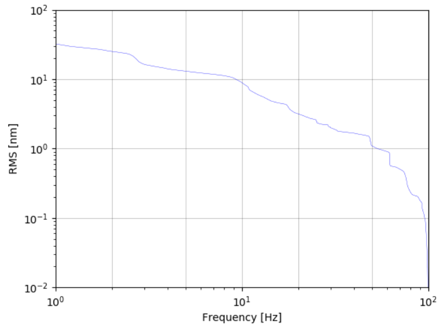


Figure 2.24: z RMS with seismometer on top of optics support inside HED-opt.

are not conclusive, as the vibrations of the cleaner didn't transmit strongly to the floor and couldn't be seen either below and on top of the support.

2.3.2 Measures on top of beam support table

Most of the measurements we did on top of devices were done in the HED-exp and HED-opt rooms, where no heavy work was not being carried and we were asked to place the seismometer on some of positions next to the beam and on top of the HED vacuum chamber. We could also do the same measurements next to this positions down on the floor, for comparison. In figures 2.25 and 2.26 we can compare vibrations in the z direction when placing the seismometer either below and on top of a support table for the beam pipe.

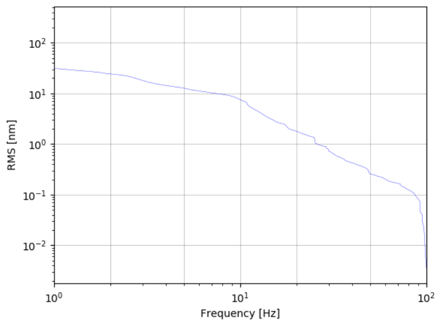


Figure 2.25: z RMS with seismometer below table support for the beam pipe inside HED-exp.

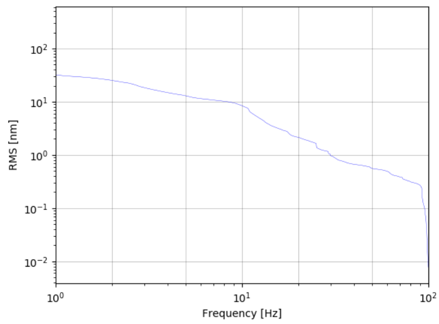


Figure 2.26: z RMS with seismometer on top of table support for the beam pipe inside HED-exp.

As one can see, there's no difference at all. However, when looking at the same positions with the E-W direction sensor, we get quite a different result, which can be seen in figures 2.27 and 2.28. In this case, though, some increment on the vibrations can be seen when measuring on top of the support. The increment,

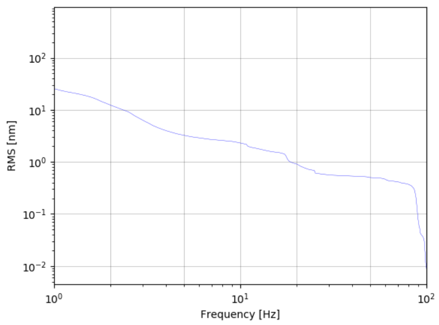


Figure 2.27: E-W RMS with seismometer below table support for the beam pipe inside HED-exp.

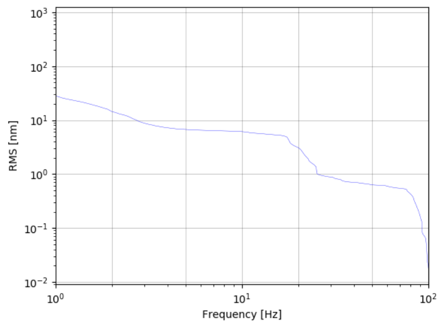


Figure 2.28: E-W RMS with seismometer on top of table support for the beam pipe inside HED-exp.

though, is only in the 20Hz region, while the 10Hz and 25Hz steps maintain the same intensity. Probably, then, this increase is due to some vibration source which is being transmitted not from the floor, but through some pipe (we did not see any working vacuum pump, so the source must be another thing). So, this pipe support is not really damping any vibration, but is nevertheless not increasing their intensity, which could also be the case.

2.3.3 Measurements on top of experiments

The same way that we can do measurements on top of support tables, we can do them on vacuum chambers along the beam lines. For example, we were able to do that on top of the HED-exp chamber, so that we could see if vibrations are worrisome when we get away from the floor. We can compare the data on top and below the chamber on figures 2.29 and 2.30. In this case, a similar behaviour to the last case happens: the vibrations that were on the floor seemed to remain there (except the 23 Hz one, but it may be a resolution issue that we can't see it, because the corresponding PSD peak looks similar in both position), while some new high frequencies are added to the spectrum. This might, as well as in the other case, come from sources other than the floor.

In both this case and the previous one, the RMS(1-100 Hz) seems to remain roughly the same. That's because no low frequencies are added between the two positions, and those are the frequencies which mostly contribute. However, we might be more

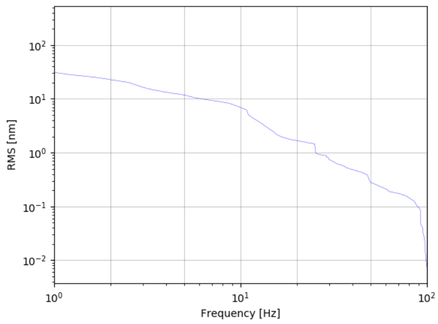


Figure 2.29: z RMS with seismometer below HED-exp chamber.

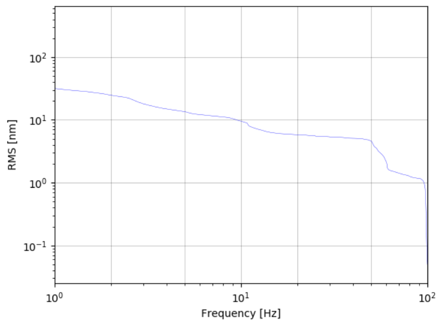


Figure 2.30: z RMS with seismometer on top of HED-exp chamber.

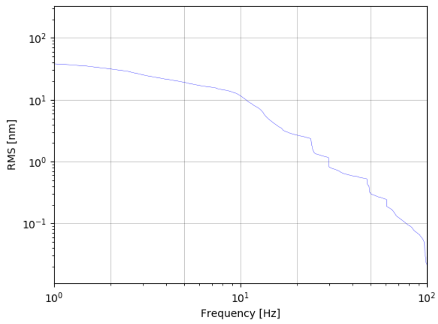


Figure 2.31: z RMS with seismometer below SQS-exp chamber.

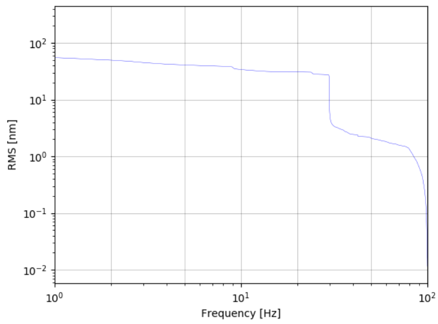


Figure 2.32: z RMS with seismometer on top of SQS-exp chamber.

interested in RMS(5-100Hz) or RMS(10-100 Hz), which are the ones which may produce a truly effective displacement. In this case we can begin to see differences between measurements on the floor and on experiments or tables. For example, in figures 2.27 and 2.28 we see that RMS(5-100 Hz) increases from 3nm to 7 nm. The same thing is observed on top of the HED-exp vacuum chamber, where this RMS goes from 3nm to 30nm. The same thing for N-S vibrations. So, the behaviour at HED-exp happens only for horizontal vibrations. Might be the case where there's a source emitting non-vertical vibrations, or that the experimental supports are worst at damping horizontal vibrations.

We also did a similar measurement in top of a SQS-exp chamber, while some of the vacuum pumps in their room were working. A comparison between a measurement on the floor and on the chamber can be seen in figures 2.31 and 2.32. In this case we see a huge difference between one case and the other: on top of the chamber there is a huge step on 30Hz which is much weaker than other frequencies, while all the other steps which appear on the floor can't be seen on top. The 30Hz is a known frequency which comes from vacuum pumps, so the conclusion is clear: the vibration getting to the experiment is not coming from the floor, but from the pipes (in this case, the ones connected to the pipe). The strength of this vibration (around 50nm) is not to be taken slightly. However, as the pumps which are in the room don't seem to emit in the 30Hz frequency, this vibration may come from provisional pumps which won't be on when the experiment takes place. In the E-W and N-S direction a similar behaviour happens, with the 30Hz huge step also appearing. However, only in the E-W direction (that means, parallel to the beam) a huge step also appears around 9Hz. It has an intensity of 25nm and should not be neglected, because it won't be coming from the pumps, so its minimization is more difficult.

3 Conclusions

Using the 500MB of data I have produced in just a month and a half, I have been able to locate the vibration sources of two characteristic frequencies inside European XFEL: 49Hz comes from chillers and electronics, while 30Hz (plus 60Hz and 90Hz) and 25Hz come from some vacuum pumps. However, I have measured that these vibrations don't produce wide displacements, so experiments should not be in danger unless some strange behaviour happens.

But most importantly, I have studied the different ways for vibrations to transmit from sources to experiments: while the floor is not a good transmitter because waves have a little transmission coefficient from pumps to concrete, the pipes appear to be the main culprits on vibration transmission. Good decoupling and damping structures are needed in these pipes, and experimentalists must be aware of this issue to prevent further noise or malfunctions in their experiments. In addition, I have seen that optical supports and chambers maintain the same vibrations from the floor on top of them, while other frequencies coming from other sources (mostly through pipes) are added.

Even though it has not been written in this report, I have also helped the PSPO group by building a Python program for RMS data visualization, and I have reported my results to the different experimentalists groups that work in XFEL, hoping the info I got could be of use for them. I have tried to collect all the knowledge I have learnt during this experience and write it down for next person who has to do a similar work to mine.

4 Acknowledgements

Firstly, I would like to thank my supervisor Sabine Cunis for making working in a big facility such as European XFEL so friendly and easy, helping me with all my doubts and trusting me with this project. She made a simple office seem like a cosy home, and gave me the freedom I needed to make this project my own.

Thanks a lot to Gerd Wellenreuther for the Python program and the laptop, but mostly for his advice and super-brief lessons that helped me find the way (or at least, a way). Also, to the entire PSPO group for making me feel like one more, and specially Konrad Piorecki for the jokes and the interest he showed. I may run out of thanks, but all the XFEL teams that let my clumsy hands work in their delicate experiments and helped me through it should also be thanked. Finally, *eskerrik asko* to Idoia Freijó-Martín for the seismometer and helping me trying to save it (without success).

The summer program organisers must also be thanked, specially Olaf Behnke for caring about us and helping us with ideas and logistics problems of different sort. With their help, we have build a community that may be in the future of physics but, most importantly, who has grown and learnt with each other. So last but not anywhere near least, cheers to all my partners. You are brighter than an FEL and merrier than a discovery of SUSY. Times has flown by and that's on you, not on Einstein.