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LabVIEW based sound and vibration measurement system

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This presentation will describe how we have utilized LabVIEW software SW and National instruments DAQ hardware (HW) to develop a data acquisition system for measurement of sound and vibration levels. The presentation consists of two main parts. 1) A short description of some of the possibilities offered by this SW and HW solution, and why we have started an in-house development of a DAQ system based on this platform. A description of applications that we want to implement. 2) Where we are today. A demonstration of application(s) we have developed, and our experiences so far.

1 Introduction

Kilde Akustikk is a Norwegian acoustic consultancy company located in Bergen and Voss, Norway. We offer among other activities acoustical measurements. Traditionally we have used dedicated professional sound and vibration measurement systems from well known companies like Norsonic and Brüel & Kjær with 1 – 2 channel recording capacity. Data processing and analysing functionality has partly been carried out using available software delivered by the instrument manufacturer, and partly by self-made Excel sheets that use exported data from the instrument. Due to increasing number of jobs we were in need of supplementing the number of measurement instruments. In that process we looked into the possibility of using PC based data acquisition.

2 Why develop an in-house measurement system

We realized that use of PC based data acquisition system did offer some interesting possibilities for us.

- To simplify the user interface we can build applications that only includes the functionality that we really needs, and is tailor-made for the measurement tasks that we normally carry out.
- We can build applications that control existing hand held instruments from the PC. We can then have the same PC user interface for different instruments.
- Introduction of a high level programming also adds the possibility to create integrated user friendly programs for data analysis and generation of automatic test reports.
- Using off the shelf mass produced data acquisition units has the potential to reduce channel cost when duplicating systems. Lower cost would make it easier to duplicate systems between our two offices.
- Development can be carried out in periods with reduced external work load.
- New business. Possibility to build low cost applications that we can sell to clients that are in need of simple applications to monitor different noise types.

The obvious risk was that we would not be able to complete the development, or use excessive number of hours in the development without really managing to build the systems that we wanted to.

3 Data acquisition system

3.1 Software

Among our employees we did not have experienced programmers in the text based programming languages like C++. The choice of programming language was decided by the limited programming experience that existed within the company. Some of us had previously used LabVIEW from National Instruments to develop data acquisition applications in other companies.

LabVIEW would offer:

- Intuitive (for engineers) graphical programming environment. Low programming threshold for new developers.
- Easy interface to (NI) hardware. Many instrument manufacturers offer LabVIEW device drivers.
- Library with data acquisition, signal analysing and report generating functions. Many examples included in the SW package. Example code to be found on NI home pages.
- Easy to implement offsite remote control of applications.
- Possibility to implement existing code in Matlab, C and other.

To increase the readymade sound analysing and report generation functionality we also ordered two add-on packages (toolkits):

- Sound and vibration toolkit: Among several useful functions, this toolkit comes with fractional octave band analyse, A-, B- and C-weighting functions and time weighting filter functions (Slow, Fast and Impulse). These functions have certification that they satisfy relevant standards.
- Report generation toolkit: This toolkit contains functions for generating Excel and Word reports.

3.1.1 LabVIEW programming example.

The LabVIEW programming environment consists of the front panel and the block diagram. Programming is performed by placing controls and indicators on the front panel and drawing signal lines between function blocks on the block diagram.

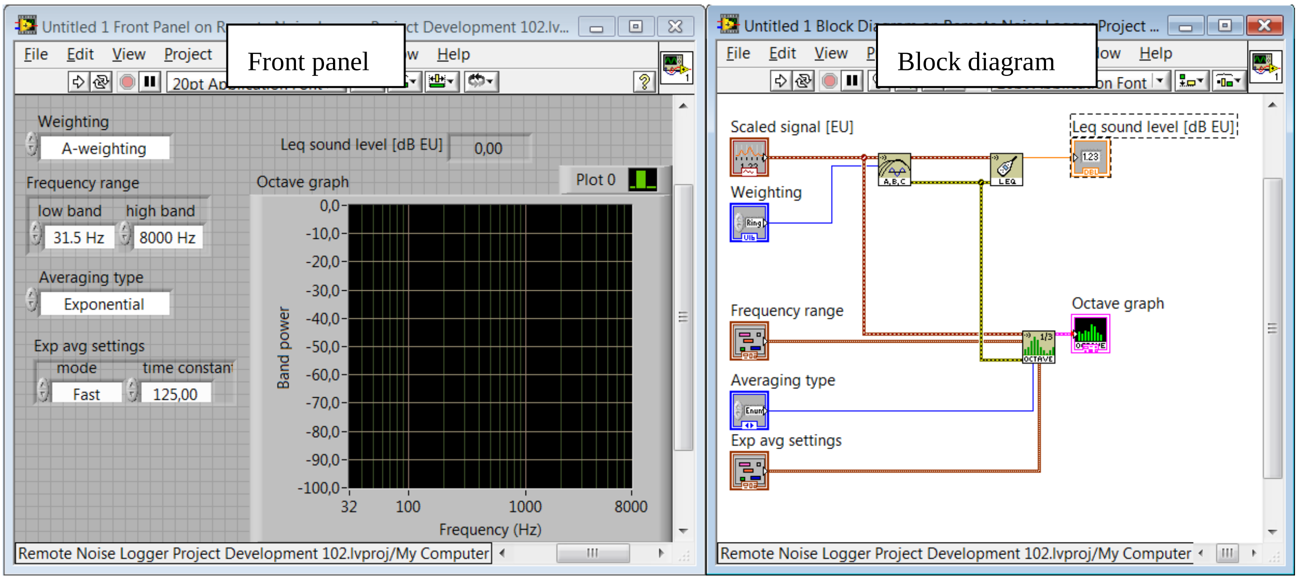


Figure 1 LabVIEW programming example. This example show sufficient code to calculate the A-weighted equivalent sound pressure level and 1/3 octave band spectra (L_{FAST}) for the input signal (Scaled signal EU).

3.2 Hardware

Having selected the SW, we decided to use NI hardware. Using the same supplier for both software and hardware we wanted to reduce the risk of incompatibility, and make it easier to request support if needed. We decided to go for the NI USB 9234.

Figure 2. Selected hardware module. NI USB 9234.

Specification:

- 4 simultaneous sampled input channels
- 51,2 kS/s maximum sampling rate/channel.
- Programmable anti aliasing filters
- 24 bits resolution, 102 dB dynamic range.
- ± 5 V fixed input range.
- Software selectable AC/DC coupling.
- Software selectable IEPE signal conditioning -> TEDS/ICP sensors can be connected directly to the input
- NIST traceable calibration.
- Meets requirements for a class 1 instrument specified in IEC 61672-1:2002.

Modules/channels can be added by connecting several units to the USB port. A chassis is available that can contain several of these USB units. The USB series (CompactDAQ) also comes with modules for analog output, and other sensor interfaces (ex bridge sensors, thermocouples, RTD sensors) to add functionality if needed.

The 9234 unit does not have programmable gain or 200V polarization voltage for our existing microphones. As interface to our microphone/preamplifiers we use NOR336 microphone front-end that provides both these function. The main disadvantage with this solution is that the SW has no way to control/verify the gain.

The 9234 has options that include USB, Ethernet or wireless connection to PC.

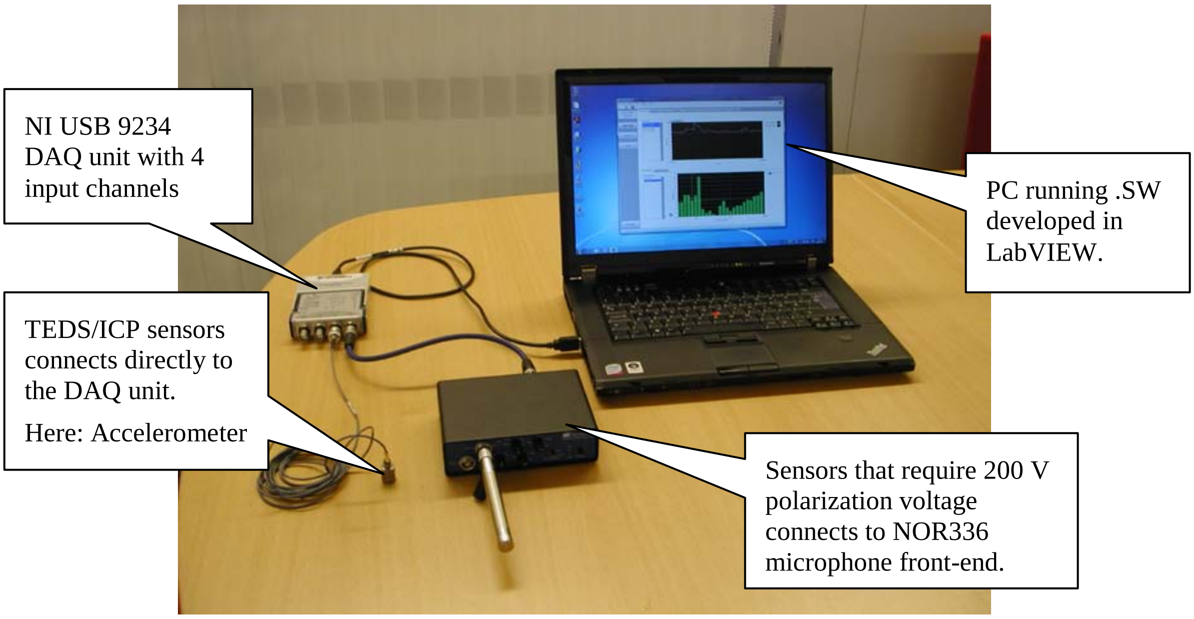


Figure 3. Complete system setup.

4 Planned applications

For 2009 we planned to develop a simple environmental monitoring system with the following functionality:

- Continuously and reliably log data to file without supervision.
- Possibility to follow the test status from an offsite location
- Measurement parameters: $L_{A,eq,t}$, $L_{C,eq,t}$, $L_{AF,max}$, $L_{CF,max}$. Preferably 1/3 octaveband values.
- Sensor calibration.
- Timer.
- Event trigger for sound recording and later analysis.

For 2010 we want to continue the development of the environmental monitoring system, and implement an application that can be used to measure reverberation time based on swept sine swept technique.

5 Status

5.1 Environmental monitoring system

5.1.1 Implemented functionality

We have developed software that fulfils most of the requirements set to the planned environmental monitoring system. The user interface is built using a combination of tab’s and pop-up windows.

Figure 4. Main test window. Test and hardware setup is located in the different tabs.

The DAQ system has implemented the following functionality within the different tab's:

- "Test Display": Viewing live data presented as level timeseries, octave band and raw data (Amplitude display tab).
- "Test oppsett": Selection of test duration, data resolution and logged parameters.
- "Data input": Calibration and setting of other channel specific setup like fixed preamp gain and channel names.
- "Test utførelse": Specification of where to store files, and other file related information. Setup of e-mail and selection of information to be sent at regular intervals. There are two options. Picture of the 'test display' and/or triggered data.
- "Trigger/timer oppsett": Setup of timer controlled recording and trigger level and trigger conditions.
- "Program status": A list of program activity.

5.1.2 Remaining work

Triggered data are saved in separate files, but the continuously logged data are stored in one file. The size of this file will grow very large as time goes on, and we have to implement a better way to manage the data volume.

We will also have to work on the offsite control part of the system. The current system sends e-mail to verify that the system is OK, but we would like to be able to control the application from a remote location

In house testing indicates that the recorded levels match those of professional sound level metes, but we will have to carry out an external verification/calibration of the system.

6 Example. Localization of origins for sudden loud noises in a concrete building

In this example we made use of the 4 channel simultaneous sampling capability and trigger functionality of the designed measurement system to find the causes of sudden loud noises ("bang") in a concrete building. The system registers events in concrete slab and stores the "raw data" from the sensors for later analysis. In an early investigation phase it was suspected that the origin of the "bangs" were from the exterior gallery

6.1 Measurement setup

We used to types of sensor connected to the measurement system:

- One force Transducer (with IEPE, constant current powered)

- Three accelerometers (Two with IEPE interface, one accelerometer with charge output connected to the NI 9234 through a charge amplifier).

It was used to different measurement setups to identify where the events was coming from.

6.1.1 Location of the force transducer, both measurements setups

In both measurement setups, the force transducer was placed between the internal concrete slab and the external concrete gallery using a bolt in the concrete slab and an angle on the gallery, see the sketch below. The force transducer measures the <u>change</u> in horizontal force in Newton[1]. The force in Newton is positive (compression) or negative (tensile).

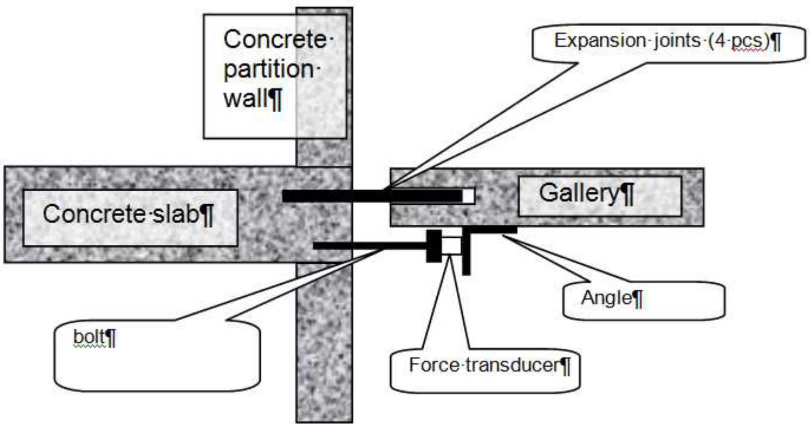


Figure 5. Sketch of the location of the force transducer (not in scale)

[1] Newton is defined as mass x acceleration, ie 1 N = 1 kg x m/s^2. Where only gravity works (9.81 m/s^2), the force on a mass of 1 kg is approximately 9.81 N.

6.1.2 Location of the accelerometers, measurement setup one

Initially it was placed two accelerometers under the gallery at level 3 (ceiling level 2); one under the extension joints, and one approximately 3.5 m into the gallery. The third accelerometer was placed in the ceiling in a small bedroom (level 2), approximately 6 m from expansion joints, see Figure 6.

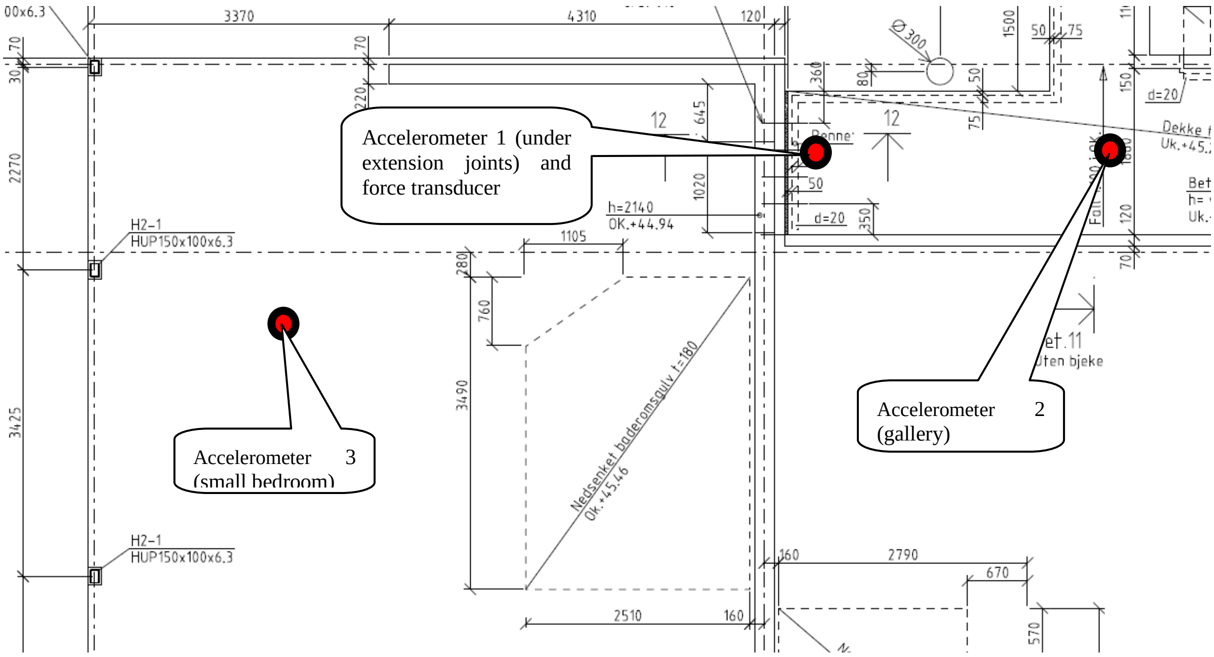


Figure 6. Positioning of accelerometer 1, 2 and 3 during measurement round one (not in scale).

6.1.3 Location of the accelerometers, measurement setup two

In the second measurement setup, the three accelerometers were located in the ceiling in the hall (level 2); one accelerometer near the expansion joints, one near the exterior wall and one near a bathroom wall (light wall), see Figure 7.

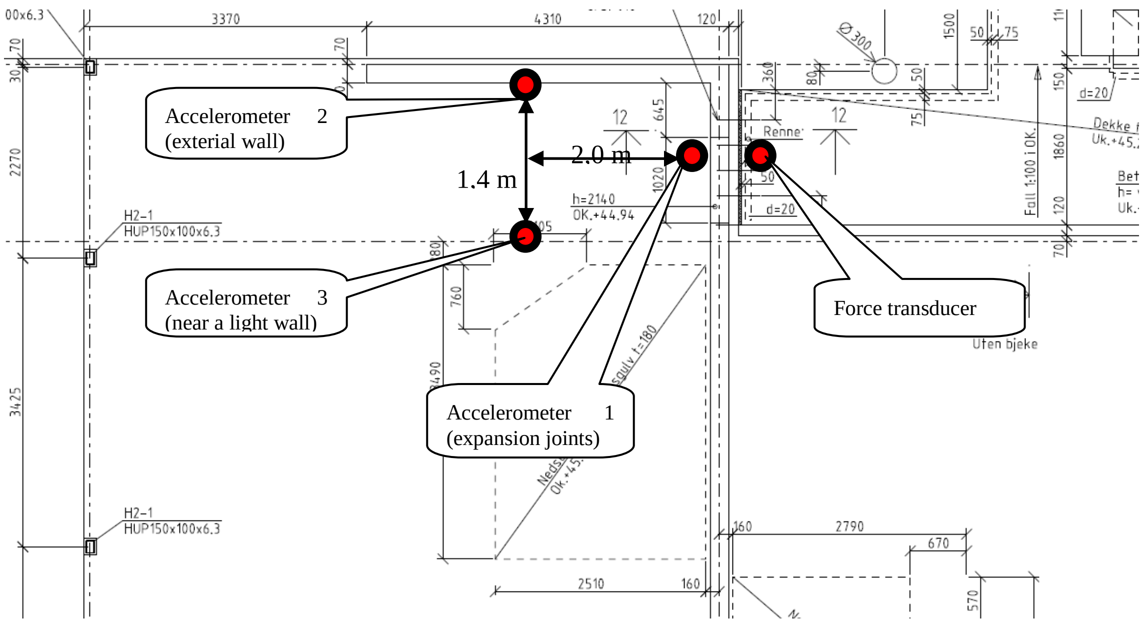


Figure 7. Positioning of accelerometer 1, 2 and 3 during measurement round two (not in scale).

6.2 Some results from measurement setup one

Figure 8 shows one day by accelerometer 1 (under the expansion joints) in the period 12:00 on 8/2-2010 to 12:00 on 9/2-2010. Figure 9 shows the temperature fluctuations in this period.

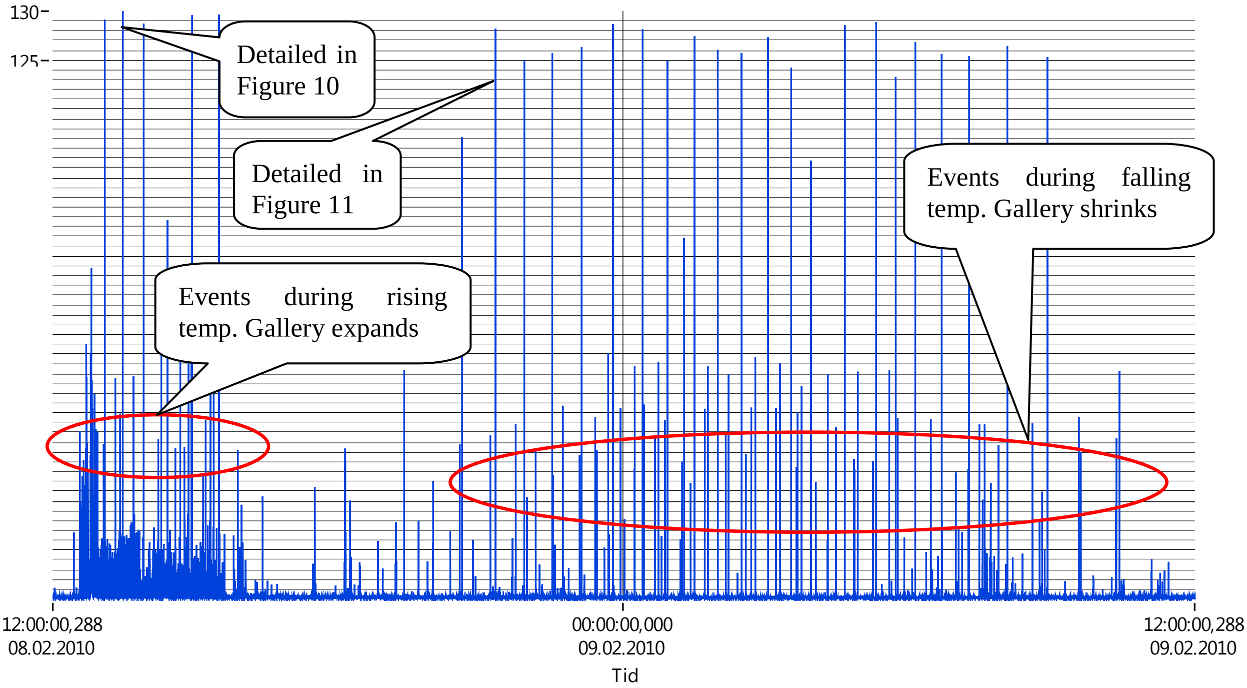


Figure 8. Accelerometer 1, events near the expansion joints on the gallery, (X-axis is time, Y axis is the acceleration level in dB with reference value: 1×10^{-6} and time-weighting "Fast"/125 ms).

Acceleration levels above 100 dB are identified as events at/near the measured expansion joints. Acceleration levels between 75 to 100 dB are identified as events from elsewhere (other end of the gallery or gallery at another level).

6.2.1 Temperature variation

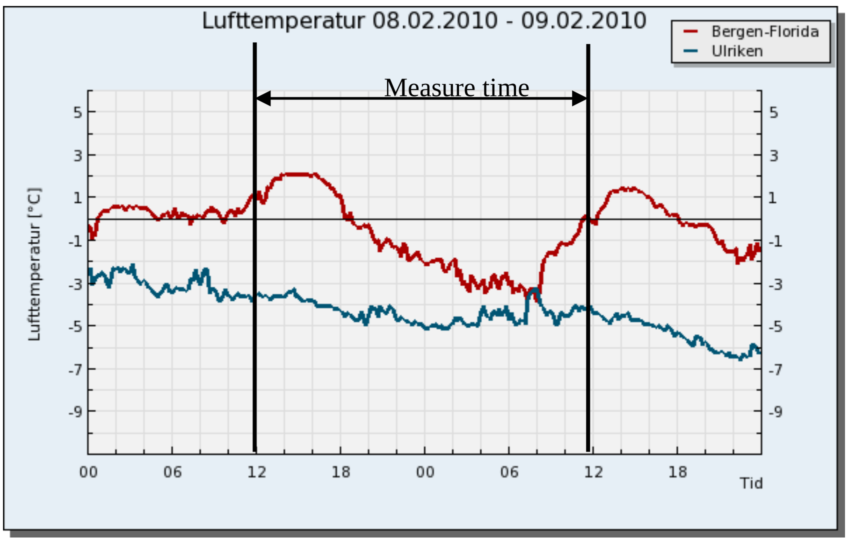


Figure 9. Air temperature at Florida (near Bergen center) and the mountain Ulriken in the measurement period (from the Geophysical Institute, University of Bergen)

6.2.2 Rising temperature, gallery expands

Figure 10 below shows all the sensors detailed at an event during positive temperature change (gallery expands), see Figure 8 and Figure 9.

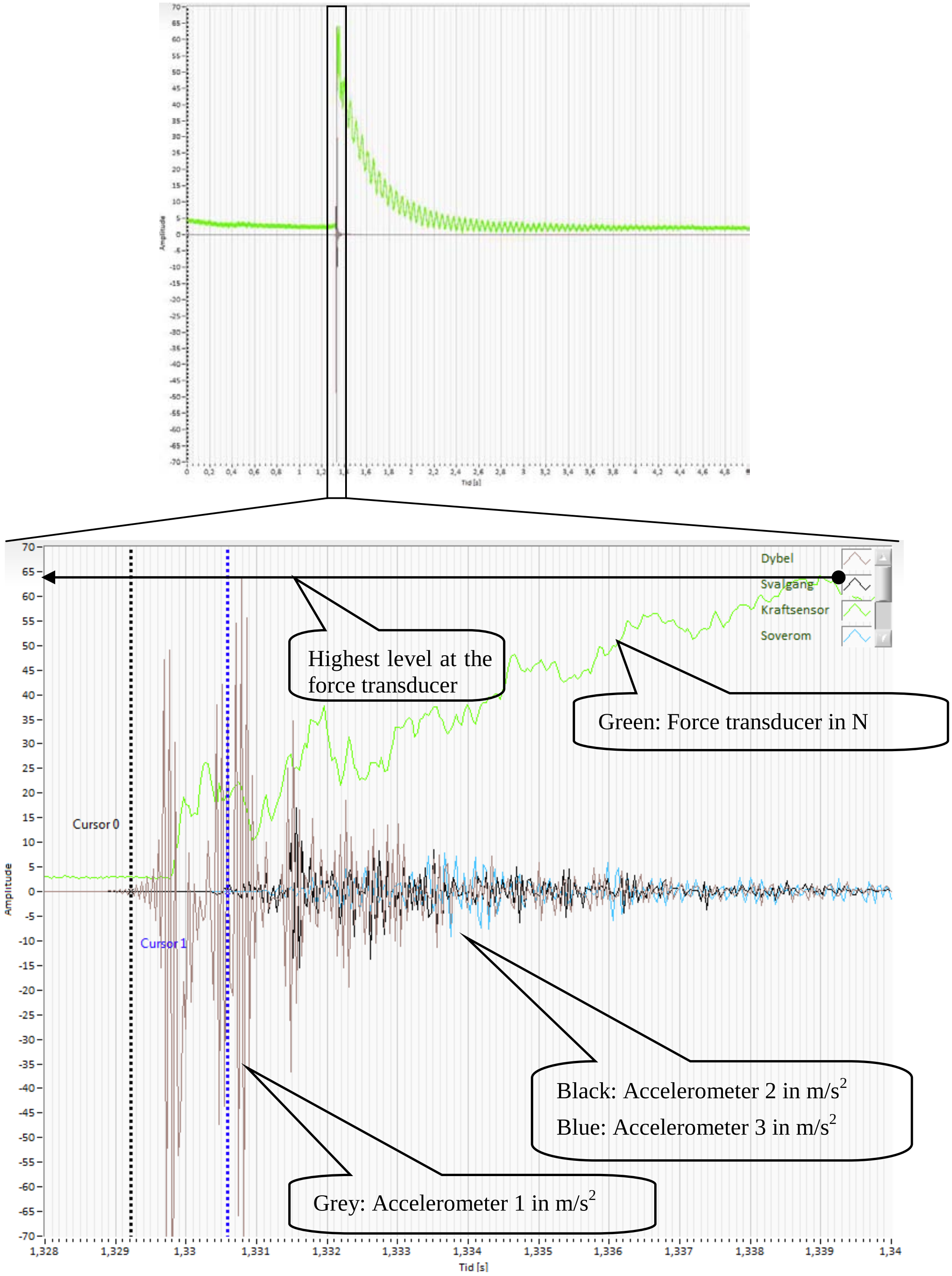


Figure 10. One event during positive temperature change (X-axis is time in seconds, Y axis is the linear amplitude of acceleration in m/s^2 for the accelerometers and Newton for the force transducer).

The green curve shows the change of force in Newton. Positive change in force indicates increased pressure on the sensor. This may be due to the gallery expands. The force transducer does not measure static force (the sensor is AC connected) and therefore fall back to "0" afterwards.

The time between the "Cursor 0" and "Cursor 1" is approximately 1.4 ms. This corresponds to approximately 3.5 m at a speed of 2500 m/s in concrete[2], see the distance between the accelerometer 1 and 2, Figure 6.

The vibration pulse is highest, and hits accelerometer 1 (at expansion joints) first (of the 3 accelerometers). The force sensor provides a positive impact of about 65 Newton. The impact on the force sensor happens almost as the same time as the vibration pulse hits accelerometer 1.

6.2.3 Falling temperature, gallery shrinks

Figure 11 below shows all the sensors detailed at an event during negative temperature change, see Figure 8 and Figure 9.

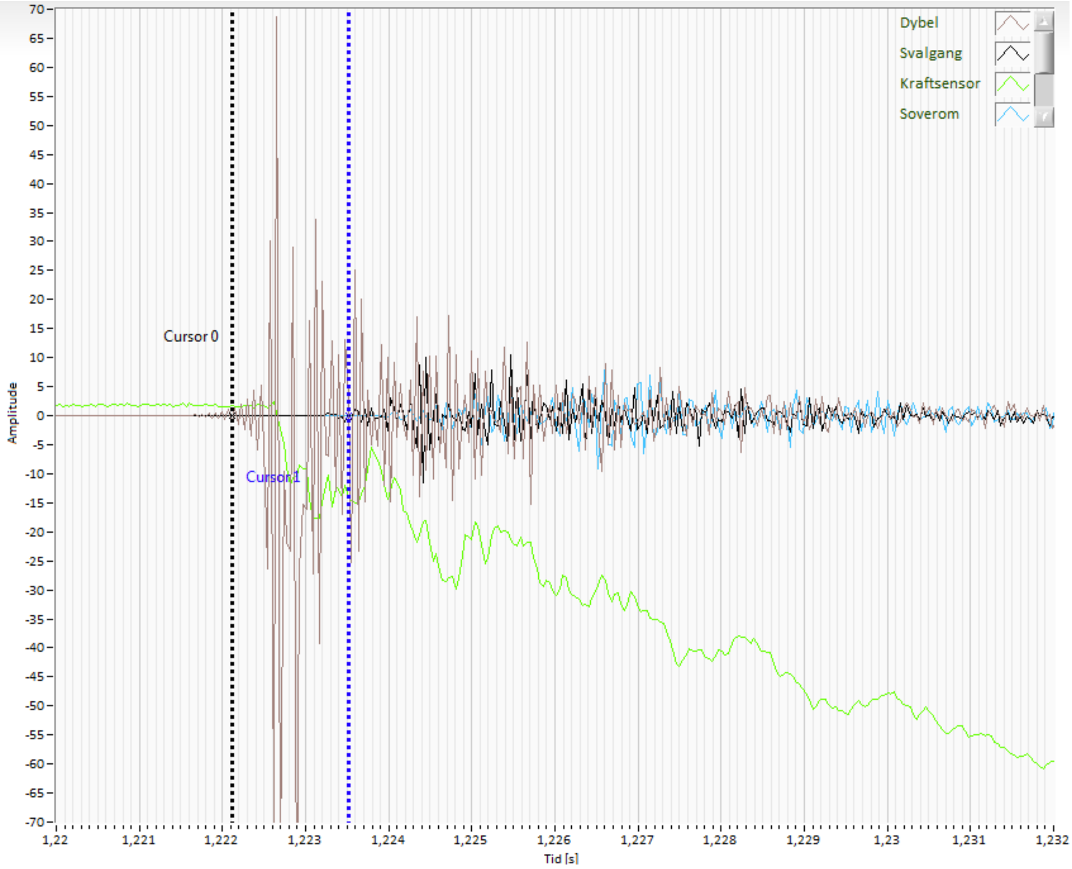


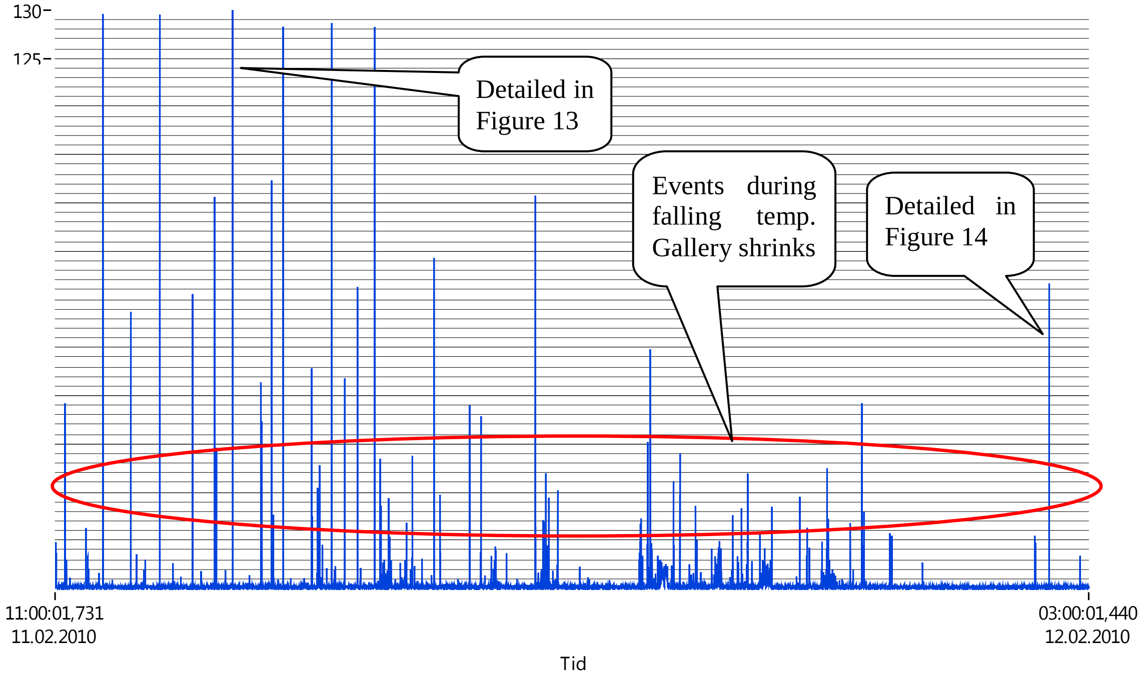
Figure 11. One event during negative temperature change (X-axis is time in seconds, Y axis is the linear amplitude of acceleration in m/s^2 for the accelerometers and Newton for the force transducer).

The distance between Cursor 0 and Cursor 1 is approximately 1.4 ms. This corresponds to approximately 3.5 m at phase speed of 2500 m/s (see the distance between the accelerometer 1 and 2, Figure 6)

The recorded vibration pulse hits accelerometer 1 (at extension joints) first. This accelerometer also records the highest level. The situation is very similar to the positive temperature change, but the force transducer provides a negative level of approximately 60 Newton. This may be due to the gallery shrinking with falling temperature.

[2] Phase speed (the speed a single wave propagates with) of the transversal sound waves ("shear waves") in concrete is approximately 2500 m/s, while the phase speed of longitudinal sound waves ("plane waves") is approximately 4000 m/s. The accelerometers used in this measurement setup, mainly measures the transversal sound waves.

6.3 Some results from measurement setup two



- *Figure 12. Events on the concrete slab near the extension joints, accelerometer 1 (X-axis is time, Y axis is the acceleration level in dB with reference value: 1 x 10^{-6} and time constant: "Fast" /125 ms).*

6.3.1 Rising temperature, gallery expands

Figure 13 below shows all the sensors detailed at an event during positive temperature change (gallery expands). Accelerometer is now moved inside, to the ceiling of the concrete slab, see measurement setup two, Figure 7.

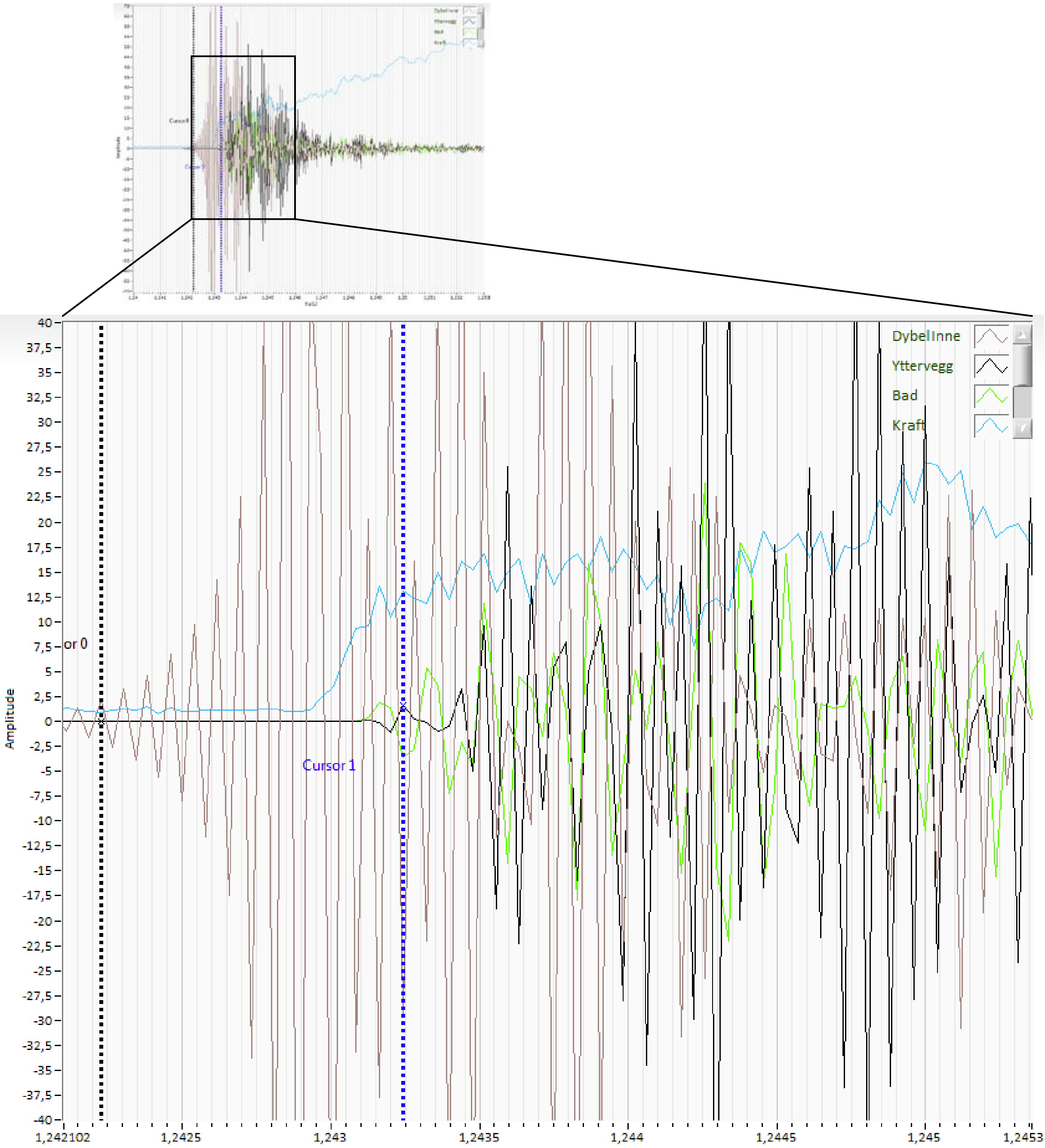


Figure 13. One event during rising temperature, measurement setup two (X axis is time in seconds, Y axis is the linear amplitude of acceleration in m/s^2 for the accelerometers and Newton for force transducer).

The time distance between Cursor 0 (initial start, accelerometer 1) and Cursor 1 (initial start, accelerometer 2 and 3) is approximately 1.0 ms. This corresponds to about 2.5 m at a speed of 2500 m/s. This corresponds well with the distance between accelerometers 1 and 2 and between accelerometers 1 and 3 (distance approximately 2.44 m) for measurement setup two, cf, Figure 7.

The vibrational pulse have the highest level and occur first at accelerometer 1 (near the expansion joints). Pulses recorded by accelerometer 2 and 3 have close to equal amplitude and arrives at approximately the same time. Together with the results from measurement setup one, we have an indication that the origin of the events are near the expansion bolts of the gallery.

6.3.2 Rising temperature, gallery expands. Events from another floor (?)

Figure 14 below shows all the sensors detailed at an event during positive temperature change (gallery expands). Here the origin of the event is from another location than the expansion joint closest to the measurement positions.

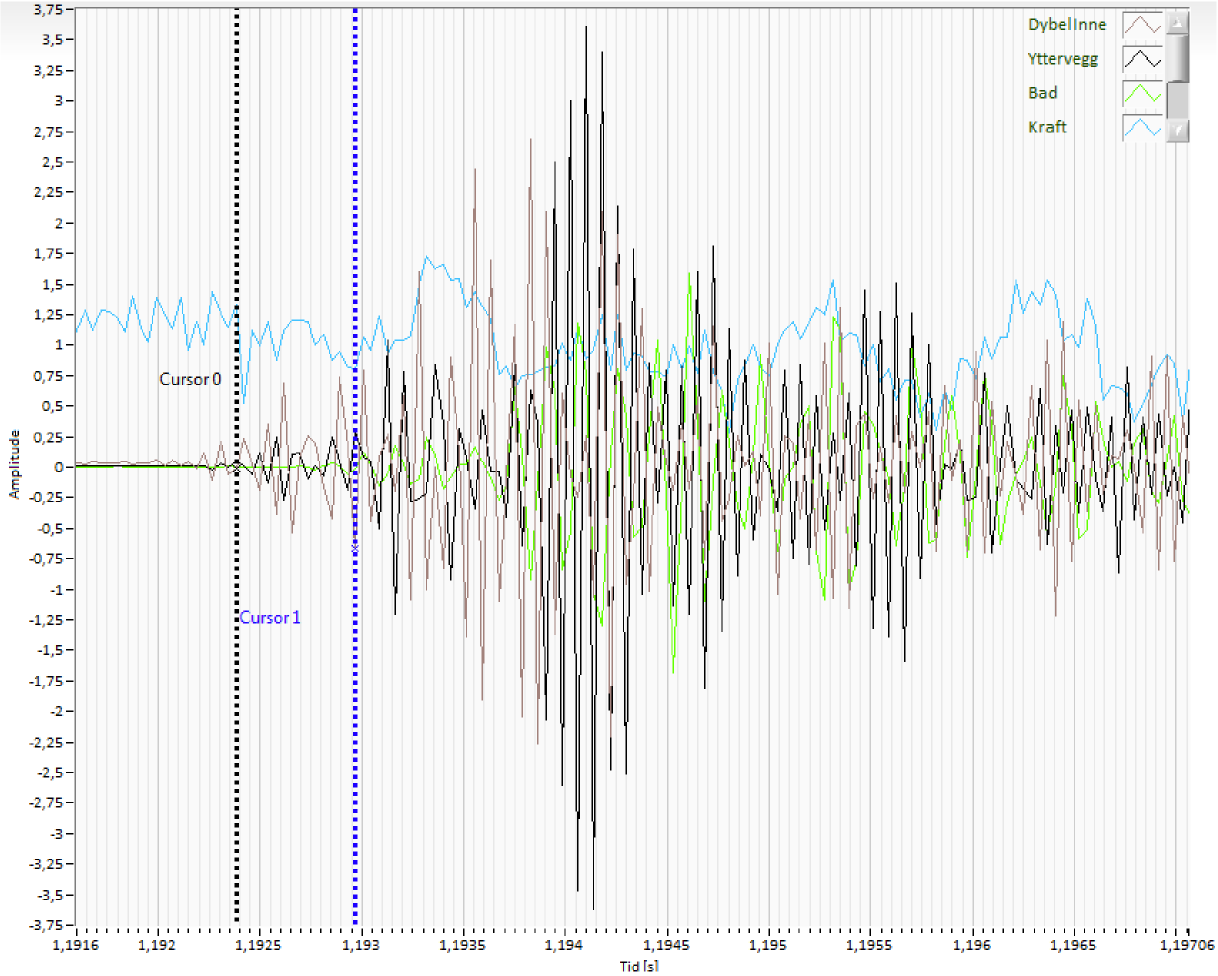


Figure 14. One Event during positive temperature change. Measurement setup two. (X axis is time in seconds, Y axis is the linear amplitude of acceleration in m/s^2 for the accelerometers and Newton for the force transducer).

The levels are much lower than in Figure 13 (Note that the Y-scale is different). Vibration pulses reach accelerometer 1 (near the extension joints) and accelerometer 2 (near the exterior wall) at nearly same time. The level of the event is highest near the exterior wall. The pulse arrives at accelerometer 3 about 0.58 ms later, corresponding to the distance between the accelerometer 2 and 3 (approximately 1.4 m at phase speed of 2500 m/s). It is likely that this event comes from another floor/gallery. The change on the force sensor is not significant in this case.

Concrete expands/shrinks very little with temperature change. The change of force (60-65 N) during the events indicates that the actual displacement is very short. This may explain why the events happen so frequently, even with small changes in temperature.

7 Example 2. Localization of origins of short noise pulses in a concrete building.

This example will describe how we used the acquisition system to locate sources of small knocks from water installations in an apartment building. It will also display some of the functionality that has been made in LabVIEW.

The building has seven concrete floors supported by concrete walls. Initial measurements showed that vibration pulses in the concrete ceiling was followed by short duration noise pulses with amplitude in the region of $L_{A,max}$ = 40 dB. The noise pulses occurred infrequently, and we were not able to locate them by listening. Amplitude/time information from the 2 channel SLM was not sufficient to identify the sources. By using three accelerometers, we planned to use differences in arrival time of shear waves at the accelerometer points to locate the noise origin.

7.1 Measurement setup

We decided to use the 4-channel recording capacity and triggering functionality of the measurement system.

We used 3 accelerometers attached to the concrete ceiling in the bedroom. One microphone was used to record the sound level so that we would be able to verify that vibration pulses were related to the short duration noise pulses that we were investigating.

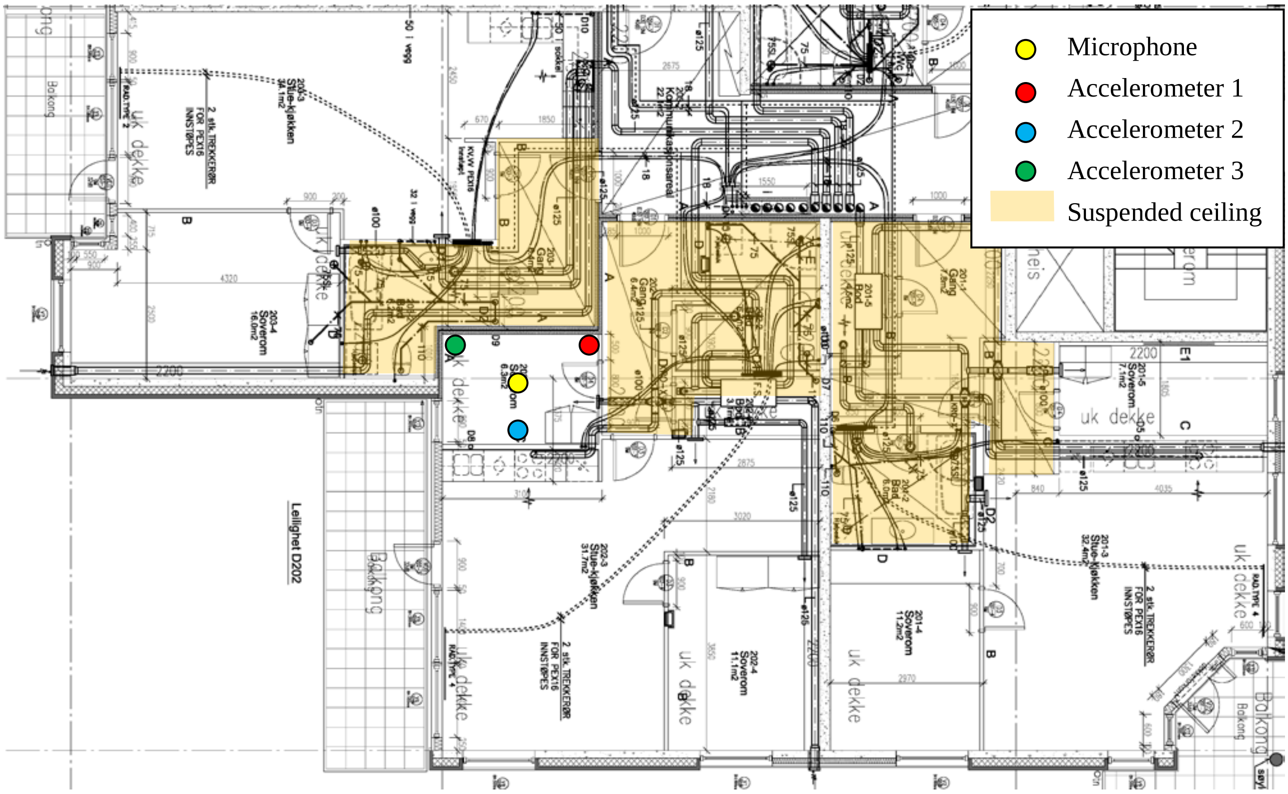


Figure 15. Test setup. Location of three accelerometers and one microphone. (Figure not in scale)

The measurement system were left unattended and logged data ($L_{A,max}$) continuously for 3 days. The trigger condition was set to $L_{A,max}$ > 75 dB for accelerometer 1. When the trigger condition was met, raw data was stored to file for later analysis. During the test duration, test status (picture of the screen) was sent by e-mail every 3 hours. The system would also send up to a maximum of 3 triggered raw data files by e-mail every hour.

7.2 Measurement results

Figure 16 shows a short 15 minutes segment of the recorded data.

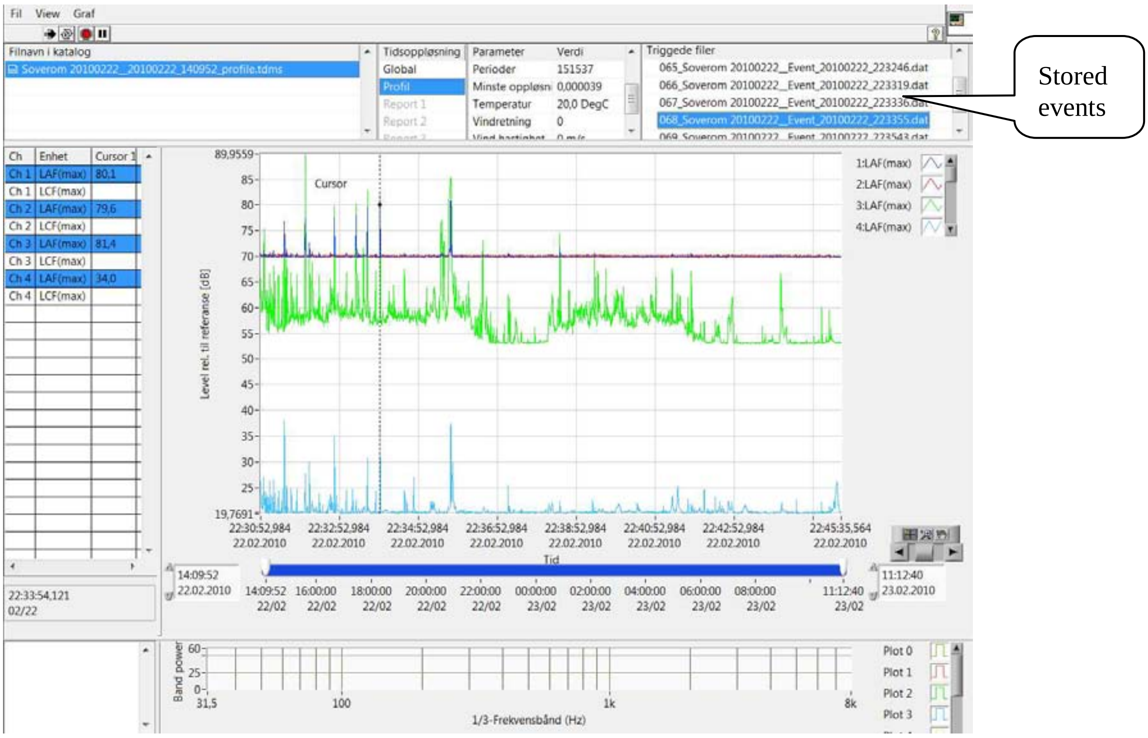


Figure 16. Recorded levels ($L_{A,max}$) during a time segment of 15 minutes. The microphone noise floor (ch 4) is $L_{A,max}$ = 20 dB. At the cursor position (black dotted line), the recorded microphone level is $L_{A,max}$ = 34 dB. In the top right window is a list of events that has been triggered in the selected 15 minutes period. The event that corresponds to the cursor position is marked with blue.

"Double clicking" a row in the event window opens the event file that contains the raw data. We have implemented some functionality in this view.

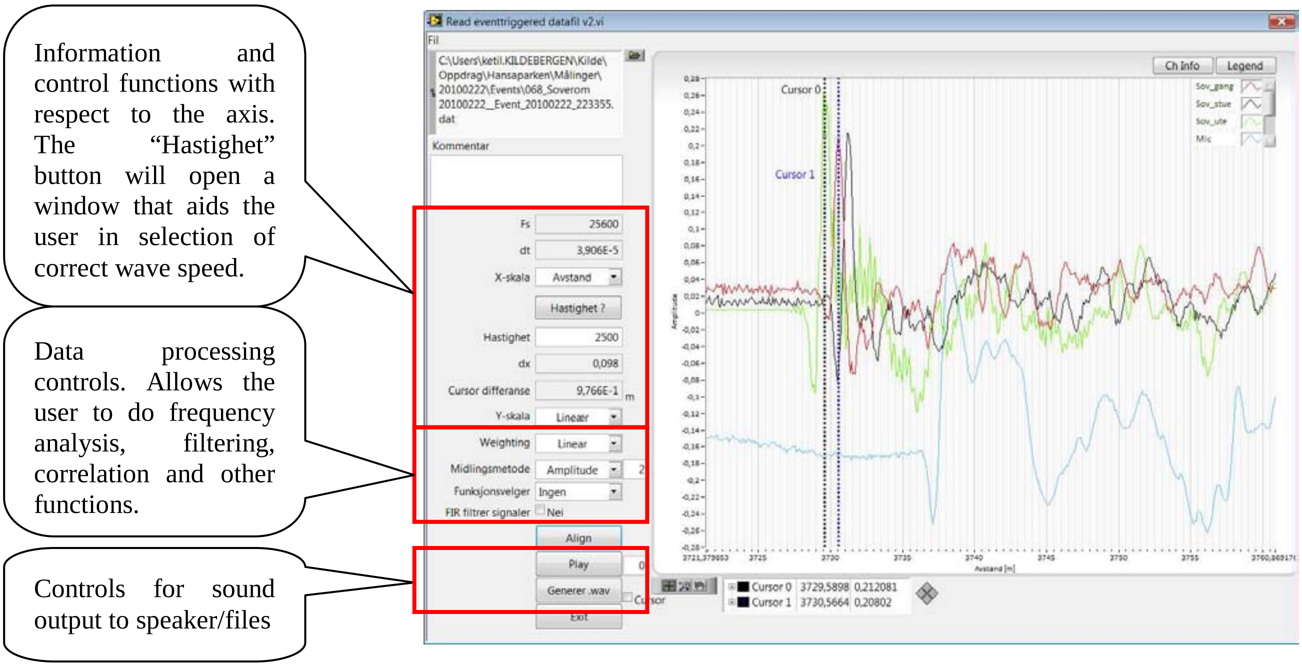


Figure 17. Recorded raw data during one triggered event. Here x-scale in m converted from time using a phase speed of 2500 m/s.

In the event showed in Figure 17, the vibration pulse arrives first at accelerometer three. Converting time to distance using a phase speed of 2500 m/s, the distance from accelerometer three to accelerometer one, and accelerometer three to accelerometer two is 0,98 m and 1,56m respectively.

These distance differences are interpreted as differences to the noise source from the different accelerometer positions. The missing variable is now the distance from the noise source to accelerometer three (first arrival). In order to help locate the origin we made a small application that draws circles around each measurement position. The measured difference is translated to difference in circle radius around each accelerometer position.

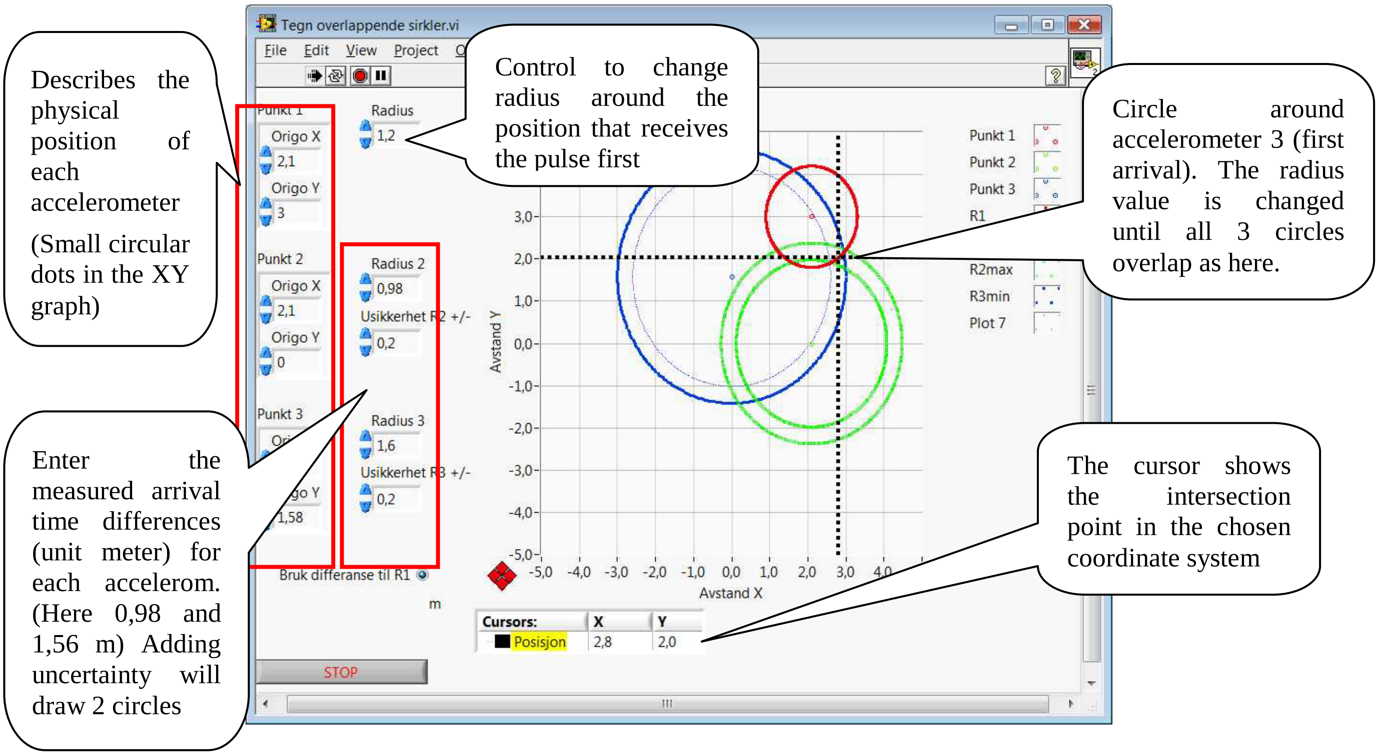


Figure 18. Program to identify probable location of the noise source.

Translating the cursor reading to the actual position in the building we identified the source to be located as shown in Figure 19:

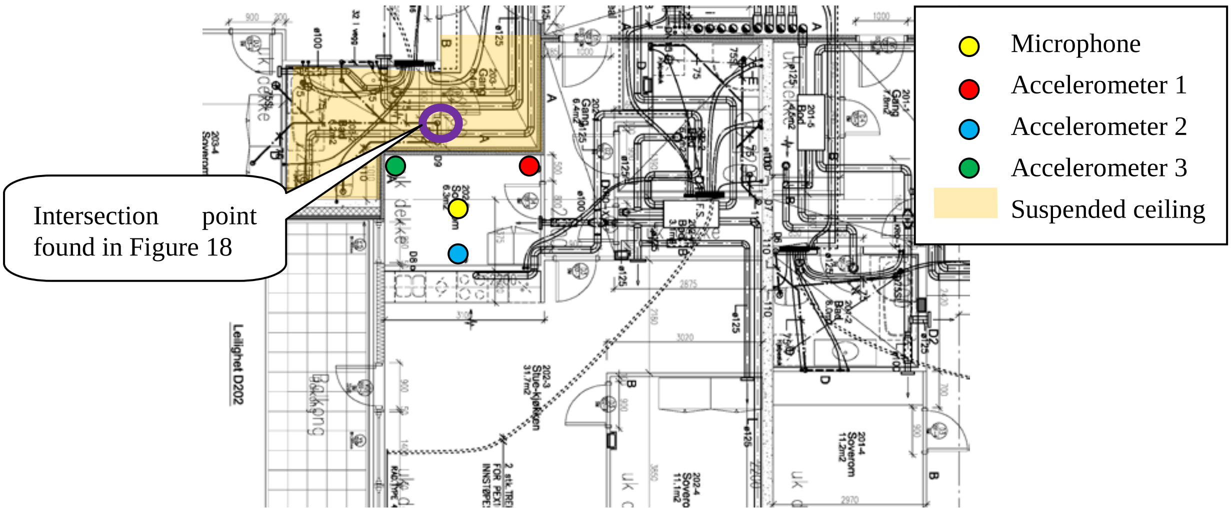


Figure 19. Identification of noise source. (Figure not in scale)

The suspended ceiling was removed and we found the source within the identified area.