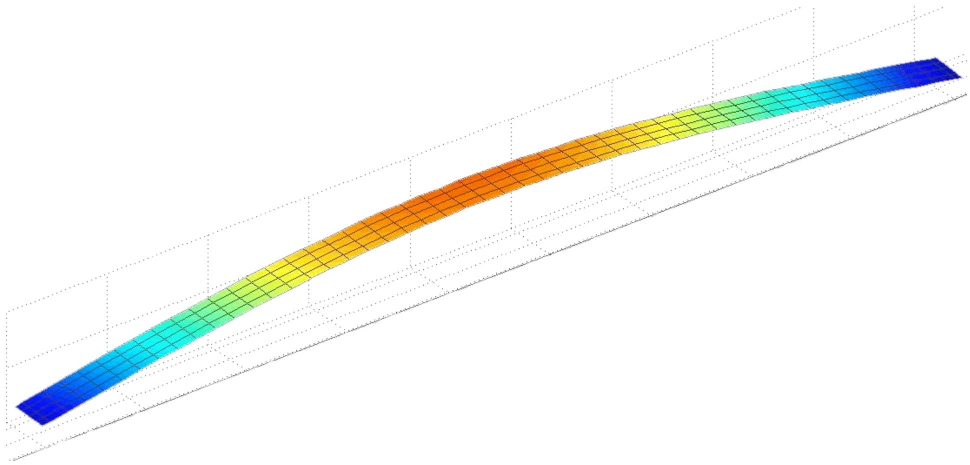

Sound and Vibration Measurements

Laboratory work 5/6:

Basic Vibration Measurements/
Laser Doppler Vibrometry

Goals: Gain experience with the preparation, setup, execution, and post-processing of vibration measurements using accelerometers, force transducers and laser vibrometry. Learn how to use the measurement data to analyse and describe the dynamic behaviour of a simple structure.

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Contents

1 Introduction

This laboratory work gives an introduction to vibroacoustic measurements. One goal is to learn how to use different types of transducers (e.g. accelerometers, force transducers, or a Laser Doppler Vibrometer (LDV)) and exciters (e.g. electrodynamic shakers) for vibration measurements. You should also get an idea of the strengths and weaknesses of the each transducer types (e.g. accelerometer vs. LDV). The second goal is to learn how to use the obtained information to describe the dynamic properties of a simple structure, in this case the plexiglas beam shown in Fig. 1. After the lab you should be able to properly select, calibrate, mount, and setup accelerometers, force transducers, LDVs, and shakers for use in experimental work.

The laboratory progresses from basic transducer handling and setup to performing different measurements (of increasing complexity) of characteristic frequency response functions of a simple test structure.

The following topics are covered in the laboratory work:

- Basic theoretical knowledge about the working principles of the transducers,
- interpretation of the information provided in the transducers' calibration charts and instruction manuals,
- setup of force transducers, accelerometers and LDVs for shaker excitation measurements,
- setup of charge conditioning amplifiers
- setup and usage of a universal data acquisition station,
- setup and usage of a dedicated LDV data acquisition station, and
- analysis and interpretation of the acquired data to describe the physical behaviour of a vibrating beam.

Figure 1: The plexiglas beam.

Using both accelerometers and a scanning LDV to measure the same structure in this lab serves two major purposes:

- It allows you to compare the two kinds of transducers and see the similarities and differences, not only in terms of measurement results, but also in measurement setup, effort, time, etc.
- Using the laser scanner you can easily collect response data in significantly more measurement points than just using accelerometers. You may therefore see the first part of the lab as an initial measurement from which to plan the measurements using the LDV (e.g. in terms of acquisition settings). This gives you the chance to actively prepare a measurement.

In addition, the lab is well suited to introduce the basic concepts of modal testing. Modal properties of structures can be obtained from single point measurements. However, by increasing the number of points, the modal model normally becomes more complete. Looking at both parts of the lab you will be able to discuss these issues.

2 Performing vibration measurements

2.1 Vibration measurement fundamentals and basic measurement equipment

There are generally three ways to monitor a dynamic system:

- Under working conditions,
- with a shaker excitation, or
- with an impact hammer excitation.

Under working conditions the structure is excited by the typical vibration source for normal usage. An example would be a vibration measurement of a washing machine while it is running one of the ordinary washing programmes. In other words, the measured vibrations describe the behaviour of the object under real working conditions. The vibrations are usually acquired with accelerometers or LDVs. However, there is often a wide range of different working conditions, meaning that many different measurements might be needed. Measurements under working conditions are commonly used to make sure a certain vibration limit[1] is not exceeded. Additionally, this type of measurement is also used to quantify relative changes of vibration levels caused by specific changes to the source or the structure. In the spectra of the acquired signals information about dominating components at certain frequencies can be found. As the magnitude of the excitation is unknown it is often hard to judge whether these peaks are caused by the character of the source (e.g. strong excitation at that frequency) or by an unfavourable structural design (e.g. resonances). Thus, it is often of more interest to investigate the structure (and maybe the source) on its own.

This is possible if the properties of applied excitation, i.e. its location and magnitude, are known. Typically this means that either an electrodynamic shaker or an impact hammer are used as

[1] Such a limit might for example be defined to prevent damage to the machine or its surroundings, or for the comfort or health of nearby persons.

excitation source, giving the user a reasonable level of control of the excitation strength and location. The excitation is characterised by the force delivered to the structure; it is measured with a force transducer. Accordingly, not only the output of the system (e.g. accelerations) but also the input (i.e. forces) to the dynamic system are known., If the dynamic system is approximately linear, frequency response functions (FRF) of the system can be estimated based on this information. This gives valuable insight into the dynamic behaviour of the structure.

The most common type of FRF used to analyse vibrations is the mobility Y, i.e. the complex ratio of a velocity v and a harmonic force F in a dynamic system

$$Y(\omega) = \frac{v(\omega)}{F(\omega)}\,, \tag{1}$$

where $\omega = 2\pi f$ is the angular frequency. Y is an *input mobility*[2] if v is taken at the same location as F, otherwise it is a *transfer mobility.* A practical reason for preferring the mobility over other types of FRFs (e.g. receptance or accelerance) is that the average mobility spectrum of a plate is a constant line (cf. [1, Eq. 8.23]). Plates are very common structures which are furthermore good radiators of sound. Being able to display their FRFs as a rather constant line optimises the range of the y-axis when plotting the FRF. If receptance or accelerance were used instead, the average spectrum would be falling/rising with frequency instead, meaning that a much wider range of values would be necessary to show on the y-axis. Even more important is the fact that because the mobility is based on the velocity, it is directly related to the kinetic energy of the structure as $E_{\text{kin}} \propto v^2$.

A problem with measuring the input mobility is that it is practically impossible to mount both the force transducer and the accelerometer in exactly the same position (unless an impedance head is used). However, if the accelerometer is placed sufficiently close to the force transducer a good estimate of the input mobility can be obtained. As a rule of thumb the distance between accelerometer and force should be small in comparison to the smallest wavelength to be measured. The input mobility not only gives the frequency characteristics of the structure but also the estimated power input to the structure (see [1, Eq. 4.25]).

Accelerometers give the acceleration of the structure: the mobility can be calculated by one time-integration of the acceleration signal. Displacements can be calculated by two integrations. There are two ways of performing this integration; either it is made with the built in integrator in the charge conditioning amplifiers (see [2]) or, preferably, it is made by the user when analysing the data. In the frequency domain, one integration is simply a division by $j\omega_n$, where $j = \sqrt{-1}$ and ω_n is the current angular frequency of the spectral component n.

Carrying out measurements in a particular frequency range, there is no perfect setup, only a sufficient accurate one, since

- transducers have inherent physical limitations,
- mounting of the transducers gives further limitations,
- thermal and electromagnetic noise is possibly created/recorded by the transducers and cables,
- transducer mounting might affect the test object,

[2]Also called *driving point mobility* or simply *point mobility.*

- data processing hard- and software has limitations, and
- vibrations from other sources might be present.

With the right choice of equipment and a good setup these effects are negligible in the frequency range of interest and the acquired data will be sufficiently correct. However, you always need to be aware of these limitations.

Background information on basic vibration measurement equipment can be found in the lecture slides [3] and [4]. More detailed information about equipment and measurement techniques is available from the library on Brüel&Kjærs's website [5].

2.2 Laser Doppler Vibrometry

Generally speaking, an LDV can replace accelerometers in measurement setups under certain conditions. The measurement principle of an LDV differs fundamentally from that of accelerometers or force transducers. One of the most important differences is that LDV is a non-contact measurement technique. This allows types of measurements which are not possible using an accelerometer as a sensor. However, the LDV also has disadvantages compared to accelerometers. Is is important to note that the two technologies should not be seen as competing; due to their specific strengths and weaknesses they actually complement each other quite well when used correctly.

Compared to accelerometers, LDV is a relatively young technique. Nevertheless, it has already developed into an important tool in engineering and science. Three of the most important application areas are:

- Vibration measurements of objects where "mechanical" transducers simply cannot be used. This is the case for extremely small or light objects (e.g. micro mechanical systems, microphone diaphragms, ear drums), extreme temperature environments (e.g. the control of welding processes), or when working with very high frequencies (e.g. in the MHz range).
- Vibration measurements of objects, which basically could be measured with traditional transducers, but where the presence of the transducer itself alters the system properties during the measurement. An example of such structures are musical instruments like violins, which have been measured successfully using accelerometers. However, nowadays a non-contact measurement is more elegant.
- Detailed vibration measurements of entire bodies in hundreds of points, to gain a complete picture of the vibrational properties. This is the application area of so-called *LDV scanners*, which are equipped with a pair of computer controlled mirrors to move the laser beam to different spots on the object's surface. This is a state-of-the-art technique which, for example, is used quite extensively by the automotive industry. Applications like entire scans of musical instruments and loudspeaker membranes have also been of interest.

A detailed introduction and discussion of Laser Doppler Vibrometry and the so-called scanning technology is given in the lecture slides [6], and [7]. Some additional information is also available on Polytec's website [8].

2.3 Brief comparison — LDV vs accelerometers

In cases where both LDV or accelerometers could be used in principle, the advantages of the laser technology usually arise from the non-contact principle and, when LDV scanners are available, from the computer-controlled positioning of the laser beam during measurements. However, compared to the accelerometer, LDVs also have their disadvantages.

Some advantages of LDV are:

- No mass/stiffness loading and perfectly flat frequency response of the transducer itself (no mechanical resonances). Especially the highly undesired effect of variable mass loading (moving accelerometers between different spots) is entirely avoided.
- Sometimes the effect of mass/stiffness loading might not be a problem, but there might be good reasons for not mounting accelerometers. Examples would be especially sensitive surfaces, e.g. thin membranes, which could be destroyed by mounting accelerometers, or very cold or hot objects.
- Scanning-LDV only: Time saving after the initial setup has been done, since one does not need to dismantle and remount the transducer for each new spot.
- Scanning-LDV only: As long as great care is taken not to move object or laser scanner, a high degree of repeatability is given. This means the same grid of measurement points can be measured again in exactly the same points. In case of accelerometers this is only given if mounting is done by means of washers or studs, which — since it often affects the surface permanently — may not always be applicable.

In contrast, the accelerometer scores in the following areas:

- In general, the signal to noise ratio of accelerometer signals is superior. This means that if the measurement conditions are such that no other requirement (e.g. number of points, mass/stiffness loading) demands using an LDV, the accelerometer should always be the preferred choice.
- Setting up a measurement for a few points can be done much quicker with accelerometers. Long term investigations are easier as accelerometers can usually be kept in place. Also, if it is difficult to directly reach the measurement position with the laser beam (the optical unit is quite large), choosing accelerometers is better than than setting up a system of mirrors.
- If the object undergoes large vibrations which cause the target on the surface to move away from the fixed laser spot, then measurements with LDVs are simply non-valid. In contrast, accelerometers move with the object.
- In case of very large objects (like ships) and objects under certain operation conditions (e.g. vibrations at the hub of an automotive vehicle during driving) measurements with the laser are difficult or simply not possible.

As mentioned, this lab will concentrate especially on the similarities and differences between accelerometers and LDVs. Lightweight structures and particularly sensitive objects will not be investigated. However, the use of the scanning LDV is similar in all cases, and the knowledge gained from this lab can be readily applied to such structures.

3 Pre-Study

It is mandatory to write the pre-study before you start the practical part of the laboratory work. However, due to the special nature of this lab, you are allowed to chose whether you want to hand in your written answers individually or as a group of two or four[3] students.

The pre-study report should be available to the lab assistant early enough so the lab assistant has at least a whole work day to read it (e.g. Wednesday evening if the lab is on Friday). It should contain the information described in the *Guide to the pre-study* available on the website. The questions stated below should be shortly answered in this document. The pre-study document is the basis for a short discussion with the lab assistant to make sure that you have the necessary understanding and knowledge to proceed with the lab. Note that even when you hand in your pre-study as a group, each individual student is still expected to be prepared to discuss any of the questions in this section.

Answering the questions is a requirement for passing the lab, and the answers need to be included in the final report. Note, that it is not necessary to answer the questions in a separate section of the report (unless you want to do so) — many questions can be related to the typical content of the pre-study and using the questions as guidelines might lead to a more cohesive report. However, be sure that the you clearly mark the places where you answer certain questions (e.g. with a footnote). The lab assistant will not search the report to find all answers.

Since you are allowed to formulate your answers as a group, it is also allowed that the two reports for each lab time contain identical passages for the answers to the preparatory questions. Since many answers relate to the theory section, you are even allowed to have identical theory sections. You are not allowed to collaborate with groups from other lab times[4]. As usual, all other parts of the report must be the unique work of the individual two (three) students responsible for the report.

Documents to familiarise yourself with.

- Measurement Equipment at Applied Acoustics
- Technical specifications of the vibration equipment: [9–13].
- Example calibration sheets: [14, 15].
- SVM lab 6 manual for using the LDV [16].
- You might want to (re-)familiarise yourself with the fundamentals of beam and plate behaviour (lectures 4 and 8 in *TA1* [1]) and transfer functions and coherence (*SVM, lab4* [17]).
- Optional: the theory documents mentioned in the bibliography.

[3] Three or five where applicable.
[4] Discussing things is fine, but not writing together.

Questions about the expected behaviour of the beam.

1. Geometrically, a beam is just a plate with one side being rather short. However, from a vibrational point of view there are big differences between talking about a "beam-like" and a "plate-like" behaviour. Do you know what these differences are?
2. Can you imagine how the first few mode shapes of the beam look like? Try to sketch a few of them and explain why you expect them. (You might want to have a look at the *TA1* lecture notes [1].) Hint: Don't forget to consider the influence of the boundary conditions, see Fig. 2 for the setup.
3. How do these mode shapes change when you go to higher frequencies? And how if you go to even higher frequencies?

Questions about accelerometers.

4. Why is the measurement of accelerations usually preferred over measurements of displacement or velocity?
5. Describe the general construction of an accelerometer. The piezoelectric disc gives a charge when subject to a force. How can this force be related to accelerations?
6. There is an upper limit for the useful range of the accelerometer (even if it is perfectly rigidly mounted to the test object). What determines this limit? How is this limit related to the sensitivity of the accelerometer? In which frequency range can we use the accelerometer B&K 4393V? Motivate your criteria.
7. When mounted to the test structure the upper limit of the usable range of the accelerometer is changed. In which way and why? What do you expect when mounting an accelerometer to the test object using wax, glue or a threadbar?

Questions about force transducers.

8. Explain the general construction and function of a force transducer.
9. Why is the piezoelectric element in the force transducer pre-stressed?
10. The nuts of the force transducer, one at each side, should not be screwed relatively to each other during mounting to the test structure and shaker. Why?
11. Force transducers are not symmetric. There is commonly a sign indicating which end of the transducer should face the test structure. Why?
12. Have a look at the calibration chart of B&K Type 8203 available at the course page. What are the limits of the transducer in terms of maximum force and usable frequency range?

Questions about charge conditioning amplifiers.

13. Why are charge conditioning amplifiers used? Do you need them for all accelerometers/force transducers?

14. What signal treatments can be made with the charge conditioning amplifier B&K Type 2635?
15. Which information from the calibration chart is needed to setup the charge conditioning amplifier so that a calibrated output signal is obtained?

Questions about shaker excitation.

16. What is the useful frequency range of the shaker Ling Dynamic Systems (LDS) V102?
17. A stinger (a thin metal rod) should be used between the shaker and the force transducer. Why? What length should the stinger have?
18. How can stinger resonance frequencies be tracked in measured FRFs?
19. The shaker will not be attached to the centre of the beam but very close to one of the ends (i.e. the small side, see Fig. 2). Why is that? Hint: think about the expected beam motion.

Questions about mobility.

20. Define the driving point mobility. How can it be calculated from a frequency response function giving the relation between the force and acceleration?
21. Define the concepts driving point and transfer mobility. How can you measure these quantities?
22. Sometimes the measure *mechanical impedance* is used. How does the mobility relate to the mechanical impedance?

Questions about measurement setup and data acquisition.

23. In order to animate the mode shapes of the beam you do not only have to think about your sampling in the time domain, but also in the spatial domain. What do you think how many points per wave length you need to properly animate a mode shape?
24. As any other FRF, a mobility can be expressed in form of an H_1- or H_2-FRF. What is the difference? Under which conditions to you use the H_1 and when the H_2?
25. What is the coherence? How can help it you assessing the quality of your measurement?

Questions about Laser Doppler Vibrometry.

26. Compared to ordinary light the laser beam has three properties which are essential for the measurement principle used in the LDV. Which properties are this and why are they essential?
27. What is the Doppler effect and how is it used in the LDV?

Figure 2: The freely suspended acrylic beam. × marks the excitation position.

4 Laboratory work

In the practical laboratory work you will perform measurements of an acrylic glas beam which is freely suspended as shown in Fig. 2. The main goal is to investigate the general dynamic behaviour of the beam. More specifically, in *Part I – Basic Vibration Measurements* you will identify the lowest resonance frequencies, their damping and their mode shapes, and you will estimate the frequency where the cross-sectional motion of the beam breaks up (i.e. where the cross-section is changing from moving approximately in phase over the width to where it exhibits significant spatial variations in amplitudes over the width). For this you will use basic vibration measurement equipment such as accelerometers, force transducers and shakers. In *Part II – Laser Doppler Vibrometry* you will measure the response of the beam at hundreds of points on the surface to get more detailed insight into the vibrational behaviour of the beam. The frequency settings and scan locations for this LDV measurement will be directly based on your findings from Part I of the lab. Part II will not only give you more information about the beam, it will also allow you to compare results between Part I and II of the lab; thus giving an idea of similarities and differences between the different transducer types.

Be sure to extensively document your complete setup, all of the settings and the status of just about everything during the measurements. A good documentation is essential to repeat measurements or backtrack possible errors (such as broken equipment) if the results looks strange.

4.1 Part I – Basic Vibration Measurements

4.1.1 Setup

You will learn how to handle the equipment and setup an experiment. A substantial part of the setup will be made by you; e.g. mounting the force transducer, shaker and accelerometers, and setting up the charge conditioning amplifiers and acquisition system.

Some parts of the setup are made beforehand by the lab assistant as only a limited time is available for the laboratory work. For instance, all equipment needed for the measurement is already pre-selected, purchased and collected — tasks that sometimes can be annoyingly time-consuming. Further the test object is already hanged in a freely suspended configuration, forcing the setup resonance frequencies below some Hertz.

Setup the experiment and present your setup to the lab assistant before every measurement. Do not forget to setup the charge conditioning amplifiers correctly. Describe the experimental setup in the report including a proper identification of the equipment used (i.e. serial numbers).

4.1.2 Preliminary investigations of the input mobility

Basic properties of the structure and setup
Start with some fundamental investigations of the vibrational behaviour structue. Start with measuring the input mobility of the structure in a wide frequency range. Use the coherence function to evaluate the quality of the measurement. Look at the magnitudes of the force and accelerations to see if it may explain why the coherence drops for certain frequency regions. You should also try to find the stinger resonance. Measure the background noise levels when turning off the power amplifier. Relate the background noise to the magnitudes and coherence of the measured response.

- Present your findings to the lab assistant and discuss your interpretations with them. Include interesting results and interpretations in the report.

Quality improvement at lower frequencies
Measure the input point mobility again. Try to see if you can improve the coherence at the lowest resonance frequencies by decreasing the sampling frequency while keeping the blocksize constant. A lower sampling frequency while keeping the blocksize constant gives a longer period time for each block. The limiting factor when chosing blocksize is often that you do not want spend too much time waiting for the acquisition to finish.

- Present your findings to the lab assistant before you continue the measurements. Include interesting results and interpretations in the report.

Investigation of the cross-sectional motion
Measure one transfer mobility to a position above the point of excitation close to the beam edge. Compare this FRF with an input mobility. At what frequency does the beam start have significant amplitude differences over the width? What is happening there?

- Present your findings to the lab assistant. Include interesting results and interpretations in the report.

4.1.3 Input mobility

Finally, based on your preliminary investigations specify the frequency range where valid measurements of the beam character can be made and use only this range in the following measurements. Measure the input mobility and use it to present the general behaviour of the beam character of the structure.

Include interesting results and interpretations in the report. There is a Matlab implementation [18] of the response of the beam based on the Euler-Bernoulli equations (see [1, Section 3.1.3]) at the course homepage. Run the code to calculate an input mobility. Compare your measured mobility with the calculated one (in the same figure in the report). Comparing measured data to calculated is one of the best ways to find out if the measurement *and* the calculations were made correctly. At least the first couple of resonance frequencies should agree fairly well. List the lowest measured resonance frequencies and their damping by using the half-power bandwidth method (see Appendix A).

4.1.4 Transfer mobilities

You should now measure transfer mobilities that can be used to find the mode shapes of the lowest resonances of the beam. This can be made by measuring the transfer mobility to a number of positions along the beam. Mount the accelerometer successively in different positions by using a spatial discretisation of 15.25 cm (see the marks on the beam). Do **not** forget to also measure the input mobility with the same blocksize and frequency range settings.

Using the mobilities you can (after the lab) make an animation of the displacement of the beam at the response points to see the motions at the resonance frequencies. In the report, plot the mode shapes of at least the three lowest resonance frequencies. A Matlab script [19] which can help you with the animations can be found at the course page.

4.2 Part II – Laser Doppler Vibrometry

4.2.1 Setup

The measurement setup is nearly identical to the one used in Part I. The force transducer and the shaker are mounted in exactly the same way. The only difference is that now the scanning LDV will be used to measure the surface vibrations instead of accelerometers. The most important steps for the LDV setup are:

- Setting up the positions of the laser and the measurement object.
- Adjusting the focus of the laser on the surface to obtain maximum signal strength.
- Defining the measurement plane (coordination between video image and the laser's vertical and horizontal control).
- Defining the measurement points and settings for data acquisition (frequency range, sampling time, etc).

Acquisition settings should be based on the experience from the accelerometer measurements. Other settings like signal enhancement will be discussed with the lab assistant during the measurement setup.

4.2.2 Preliminary test measurement

Perform a first measurement of a couple of points on the beam. Evaluate the data with respect to data quality, frequency range and sufficient number of measurement points for the captured "modes". Make adjustments to your settings and repeat the measurement (one or several times) until you are satisfied.

- Present your findings to the lab assistant before you continue the measurements.

4.2.3 Surface scan of the vibrating beam

Based on the settings found in preliminary measurements perform a surface scan of the vibrating beam. Note that this measurement might take substantial time (anywhere from 20 minutes to an hour or more[5]). At home, you will use the MATLAB `patch`[6] command to visualise and animate some of your data. The MATLAB script [21] can be used for this.

- The lab assistant will have a look at some of the results together with you to check the quality of the data and to give you some hints for the interpretation.

5 Additional notes on the report

Investigating the vibrational properties of structures is often not related to any standardised measurements (in contrast to e.g. measurements of the sound reduction index for walls). Or, in other words, there is no pre-determined "cooking recipe" you can simply follow. Instead you have to identify for yourself how to obtain and analyse data which is significant for the determination of the modal properties of the object. Naturally, standard measures like mobility, coherence, etc. will be very helpful for this.

A good start for the report is to look at the first parts (the accelerometer measurements) and the observations you could make there. This will influence your initial choices for the setup of the scanning LDV measurements and give you some impression about what to expect from the LDV measurements. The preparation questions should support you in this discussion.

If you then look at the measurement(s) with the scanning LDV, to what degree were your expectations fulfilled? You will also notice that some of the data is better when obtained with the accelerometers and some data is better when measured with the LDV. Indicate this with some example data and try to find explanations for these differences.

In general, it is important that you present and discuss your measurement data adequately and compare it between measurements and with theory. Do you get the same results (in terms of mobility, coherence,...)? Explain eventual differences. Don't forget to investigate possible error sources, the validity of your results and possible limitations. Which advantages and disadvantages of vibration measurements with LDV and accelerometers did you experience? Do you think one method is vastly superior to the other?

As stated above, the report should contain the answers to the preparatory questions — integrating them in your theory or method sections can be convenient. Copy and paste from the available literature is not allowed. You should present various results and discuss them to emphasise your findings and statements. Answer the questions and perform the required post-processing tasks (such as mode shape animations). Write the report in accordance with [22].

A Half-power bandwidth method

The half-power bandwidth method investigates the magnitude of an object's input mobility. Under the assumption that the mobility around each resonance is influenced only by that resonance, it is possible to find a relation between the loss factor, the resonance frequency and the half-power bandwidth at each resonance. The half-power bandwidth, $b = f_2 - f_1$, is the width of the frequency interval around the resonance at frequency f_n in which the mobility level is within

[5]As the LDV is doing all the work here you are free to do something else in this time.

[6]More information about this very useful command can be found in [20]

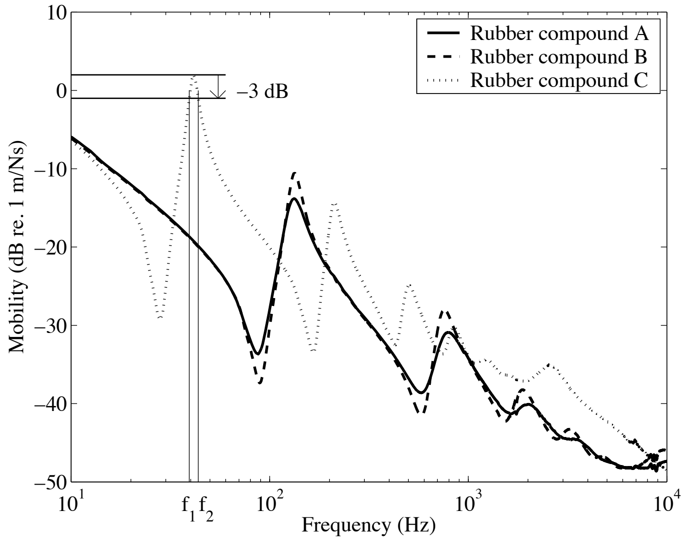

Figure 3: The half-power bandwidth. Demonstration of how the bandwidth is determined.

−3 dB of the peak value at the resonance (see Fig. 3). The loss factor η_n at the resonance can then be calculated as [23]

$$\eta_n = \frac{b}{f_n} = \frac{f_2 - f_1}{f_n} \tag{2}$$

The main limitation of the method is that consecutive resonances must be well separated. Neighbouring resonances do not only need to be distinguishable from each other, it also has to be assured that they are not significantly affecting each other. Otherwise it is not possible to find the true intersection between the magnitude of the mobility and the −3 dB-line.

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