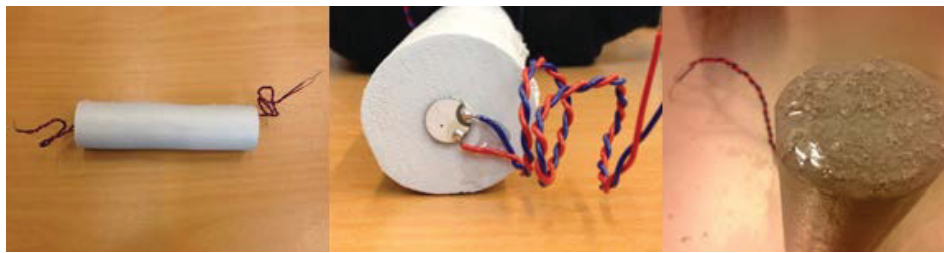




Master of Science Thesis Mechanical Engineering

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Examining the quality of extruded plastic with the nondestructive testing method NAW[®]



Eva Jansson
Seyed Saeid Taghavi

Institutionen för Maskinteknik
Blekinge Tekniska Högskola
Karlskrona
2014

Supervisors: Prof. Claes M. Hedberg, BTH
Dr. Kristian Haller, Acoustic Agree AB

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Mechanical engineering
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Abstract:

Defects in a plastic floor material produced in Tarketts factory in Ronneby are causing waste of time and material since it is noticed too late in the production line. The objective of this thesis is to investigate if the nondestructive test method NAW[®], which is developed by Acoustic Agree in Ronneby, can be a solution to find the defects at an earlier stage.

Nondestructive testing mainly means what the name says; quality tests of a material can be made without causing any damage. One simple example of a nondestructive testing tool is the human eye. By looking at a product defects on the surface can be found. The method used in this thesis, NAW[®], is a nonlinear acoustical method. By listening to the material, information about disturbances inside the material can be gathered and interpreted to get a picture of the quality status. Although by listening it does not in this case mean by a human ear but with special equipment since the sound used is high frequent ultrasound.

For several material samples, experiments were made both for the references and with introduced defects. It was hard to get definitive results since, for example, even the results for the different reference samples were differing a lot. Nevertheless there are some results pointing in the same direction which means that there is still hope for the possibility to use NAW[®] as a tool in the production at Tarkett.

One important problem in this work is the fact that the defect material is not actually a real defect material but an imitated one with defects made by hand in the experiments. This is a possible error and has to be considered in case of further experiments. Either the imitated defects have to be “improved” or, in the ideal case, real defective material from the factory should be used to get as reliable results as possible.

Keywords:

NAW[®]-method, Nondestructive Testing, Nonlinear Acoustics, Material Testing, Plastic, Ultrasonic Testing.

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We would also like to thank our laboration neighbor Ph.D. student Babak Khodabandeloo for always trying to answer our confused and maybe not very thought-through questions about this and that. At last we would like to acknowledge another neighbor in the mechanical laboratory for his help with machines and for sharing his classical experience in general, Thomas Lennartsson.

Karlskrona, October 2014

*Eva Jansson
Saeid Taghavi*

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1 Notations

A	Area
A_{def}	Area related to defect sample
A_{ref}	Area related to reference sample
B_r	Half power bandwidth
c	Sound velocity
Δf	Frequency increment relative to 1 Hz
f_l	Lower frequency (when calculating Bandwidth)
f_p	Frequency peak
f_u	Upper frequency (when calculating Bandwidth)
t	Time
u	Particle velocity in a wave
Xray	Electromagnetic radiation
y	Vector of amplitudes
ζ	Damping Ratio

Abbreviations

Amp	Amplitude
AV	Air void defect
cm	centimeter
dB	Decibel
Diff	Difference
H	Harmonic
Hz	Hertz
kHz	kilo Hertz
m	meter
mm	millimeter
NAW[®]	Nonlinear Acoustic Wave modulation
NDC	Non-Destructive Characterization
NDE	Non-Destructive Evaluation
NDI	Non-Destructive Inspection
NDS	Non-Destructive Sensing
NDT	Non-Destructive Testing
Nr	Number
PZT	Piezoelectric Transducer
s	seconds
SUM	Summation
UG	Unmixed Granulate defect
V	Volt

2 Introduction

There is a never ending ambition for companies to render more efficiency to save money and time. In many situations this is closely connected to the minimization of waste which is also profitable in an environmental, or a sustainability point of view.

Exactly this is why nondestructive testing is a very interesting and important field of science. By using nondestructive testing materials and structures can be examined without being destroyed. It means that if the examined material or part is qualified as acceptable the production involving the material or usage of the part can proceed without further examination. For example a defect can be noticed early in the production line and corrections in manufacturing parameters can be made right away. A part of a structure might be of good quality even if its suggested lifetime is over. If this can be noticed the part can be kept in use instead of being thrown away. This can help saving money, time and environment as wished for.

In this thesis, a specific material produced by Tarkett AB in Ronneby is studied. Defects in the material cause waste of material and time in the production line and therefore also money. The aim is to be able to detect the defects earlier. By using NAW[®], Nonlinear Acoustic Wave modulation, which is a non-destructive test method, defects in the material will hopefully be tracked down. First of all it has to be investigated if this method seems to be at all applicable for the purpose.

In order to use this method, ultrasonic waves are applied. Ultrasound has a frequency higher than the highest limit for human hearing 20 kHz [1]. NDT with ultrasonic has been a reliable method for many years. It is known as a classical method to test materials to detect defects in them. In order to apply the mentioned method, ultrasonic waves are sent through the material. Nowadays, due to many great advances in tools and methods, it is expected to have consistent results with low tolerances [2].

3 Aim and approach

In the production of the floor material from Tarkett there are at times some defects present which will make the material useless and it will be thrown away. This takes time from the production and would be preferred to be noticed right away when defects comes up and not as now, further down the production line. The final goal for this thesis is to have good enough results to be able to suggest a prototype of a device to measure the quality of the material directly in the production. To get there the aim is to study the material with the nondestructive test method NAW[®], Nonlinear Acoustic Wave modulation.

Important questions to summon the work are formulated below.

1. Can differences between reference material and defect material be found with the NAW[®] - method?
2. Can the pattern of differences be connected to the amount of defects introduced to the material?
3. Depending on the results.
 - a. If the results are clear and are indicating defects in a good way; how can this examination, of the material, be implemented in the production in Tarkett?
 - b. If the results are not clearly indicating the defects; have there been obvious errors in the work and in that case how can they be avoided or eliminated in future work? Can the method still be interesting for the production? What can be a possible future solution for implementation in the factory?

The questions will be answered when the results from the NAW[®] examination have been made and before that quite a bit of experimenting will be carried out. The way of handling and interpreting the results of the experiments is described in the Method chapter.

4 Theory and Background

4.1 Waves and Acoustics

Many well-known philosophers and scientists have of course been involved in wave and acoustical studies over the centuries. Just to mention a few, names as Pythagoras, Sauver, Euler and Fourier appear as important to the evolution of this just as many other scientific areas. [3] Waves are important parts in many different parts of science and since this thesis is all about using nondestructive acoustical methods for testing materials they are essentials and inevitable to enclose.

There are different ways to define a wave. One is to consider it as a mathematical model which is a time variant quantity $u(x, t)$. Waves can be interpreted by either linear or nonlinear partial differential equations. Another way to define a wave is to consider it as a disturbance passing through a medium carrying energy, but it is not making any changes in the medium itself [3].

Waves are divided into two main groups, transverse and longitudinal waves. Transverse waves, like electromagnetic waves, are oscillating perpendicularly to the wave propagation in the plane but longitudinal waves, like sound waves or earthquake waves, can oscillate along the wave propagation. Figure 4.1 shows both a longitudinal wave and a transverse wave.

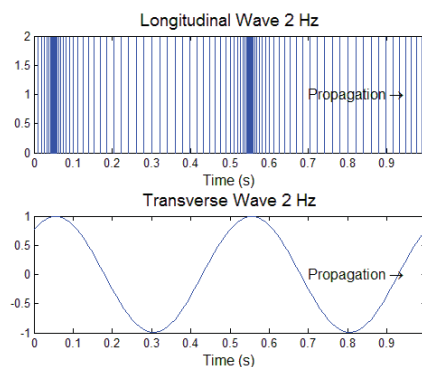


Figure 4.1. Illustration of a longitudinal wave (upper) and a transverse wave (lower).

The linear wave equation can be written as equation 4.1:

$$\frac{1}{c^2} \frac{\partial^2 u}{\partial t^2} - \frac{\partial^2 u}{\partial x^2} = 0 \quad (4.1) [4]$$

which has a general solution in equation 3.2:

$$u = f(x - ct) + g(x + ct) \quad (4.2) [4]$$

The functions f and g represent two waves travelling in opposite directions. This means that one wave, u , is often considered as two combined waves, f and g . A nonlinear wave equation is directly more complicated to solve, even this relatively simple equation 4.3 for undamped nonlinear waves:

$$\frac{\partial u}{\partial x} - \frac{\varepsilon}{c^2} u \frac{\partial u}{\partial \tau} = 0 \quad (4.3) [5]$$

where

$$\tau = t - x/c. \quad (4.4) [5]$$

The result of solving the wave equations is simply that the looks and behaviors of the wave will be known. In this thesis no wave equations will be solved or used to carry out the results. Instead it is the frequency response received after exciting the material that will be interpreted and by finding signs of nonlinearity the reference and the defect material will be compared.

4.2 Ultrasonic waves

Ultrasound is defined as the sound over 20 kHz, in other words sound with higher frequency than the highest limit for human hearing. To give some kind of conception it can be mentioned that for sound of 20 kHz travelling in air where the sound velocity is 343 m/s the wavelength of the sound waves is around 1.7 cm. Ultrasound is well suited for material testing and other areas of use for many reasons but two are mentioned to be specifically preferable. Firstly ultrasonic has the advantage, over for example electromagnetic waves, that it is travelling relatively slowly through the material. This will simply result in the ability to collect more information. Secondly the ultrasonic waves can travel through media which some other waves, for example visible light cannot. In other words the material does not have to be optically transparent

to be permeable for ultrasonic waves. [2] The advantages and the potential for development of new or improved methods explain the popularity of using ultrasonic in nondestructive testing.

Two familiar historical ultrasound generators are the Galton whistle and Koenig's tuning forks. The whistle also known as dog whistle could produce sound of up to over 30 kHz and as the name indicates it was used to study the hearing range of animals. The tuning forks are well known from musical instrument's tuning. Koenig though developed tuning forks to reach frequencies much higher than the human ear can hear. [2] Since then the usage of ultrasound has really changed. Now the ultrasound is often produced through transformation of electrical charge into mechanical waves using piezoelectric transducers.

4.3 PZT

The most usual way to transport ultrasound into and out of a medium is by using piezoelectric transducers, PZTs, which mostly means thin plates of piezoelectric ceramic material. The properties of piezoelectric materials make it possible to transform mechanical pressure to electric charge and vice versa. In other words when the PZT is exposed to electric charge its volume expands and reduces depending on the electric charges. The discoveries were made by the Curie brothers 1880-81. [6] These discoveries have been very important and useful to the field of ultrasonic testing of materials. There are transducers which are especially used for either transmitting or receiving ultrasound but also those with ability for both functions at the same time. The transducers are really important when considering the development of the efficiency of the material testing. The goal is of course to make the transducers as small as possible but at the same time as powerful as possible, which can reduce time and costs of the testing procedures.

There are different materials and sizes of PZTs suited for different areas of use. For example the frequency range should be considered when choosing the right thickness. The thinner the transducer is the higher the limit for suitable frequencies. The lower frequencies wanted the thicker transducers are needed. [6, 7]

4.4 Nondestructive Test Methods

As the name is insinuating Nondestructive testing is all about testing materials and constructions without having damaged them. The quality of a material can be valuated while the part in question is still intact, which means that if the results are satisfactory the part can continue to be used as before. This leads to less unnecessary changes of well-functioning parts and materials.

One of the most obvious nondestructive methods is the human visual ability to see cracks or defects on surfaces although it is unreliable due to human errors. Penetrating liquid is another easy and cheap way to find cracks, unfortunately only cracks that are connected to the surface of the examined material. Both of those simple methods are lacking the ability to find internal cracks and micro cracks. X-rays on the other hand can go through the materials to detect internal defects but they involve radiation risks and need strict safety arrangements. Eddy currents can also be used, but only for electrically conductive materials. Another method which seems to be good to detect defects in materials is, as mentioned before, ultrasonic waves in which ultrasound should travel inside the material with high frequency. It can be used for all materials in which mechanical waves can travel. [8] Acoustics and ultrasound seem to be perfect for the mission of material testing. By investigating the material with sound a lot of information can be found. There are different methods, either linear or nonlinear. The linear methods which have been popular for a long time are good but often more time consuming and sometimes less accurate than the newer nonlinear methods.

There are different names used to call nondestructive tests such as NDT, NDE, NDI, NDC or NDS. The common thing of these methods is that they are all dealing with nondestructive testing but are considering its own approach toward the test. For example, NDT, Nondestructive Testing, is focusing more on the test itself but NDE, Nondestructive Evaluation, also consider the evaluation or process [9]. Defects can be inspected by these methods by detecting nonlinearities. When an acoustical signal is distorted by damages in a material, nonlinearities can be found. Another way to find defects is to consider resonance frequency and its mode changes [8].

4.5 Tarkett

Tarkett is an international floor solution company. They provide many different customers with flooring solutions. Floors are produced especially for, amongst other, healthcare premises, hospitals, sports arenas and homes and sold in over 100 countries. The company is the employer of almost 11000 employees at 32 production sites at different places of the world. In Sweden Tarkett has been producing floors since 1886. Now there are two factories in Sweden located in Ronneby and Hanaskog. The factory in Ronneby is the company's largest unit for the production of homogeneous plastic floors, which is the material involved in this thesis. [10]

4.6 The material

The plastic in the production is not always of the right quality. The defects which will be examined are unmixed granulate and air voids inside the material. It is important to detect the defects sooner so that the waste of time, material and hence money can be reduced. Since the defects exist also in material which is of good quality the task is to notice the difference between accepted and unaccepted amount of air or unmixed granulate. For this thesis there is no defect material available, which means that the defects will have to be introduced manually to the reference material that is available. The imitated defects will not give the reference material the same properties as the real defects would. Nevertheless the results will show if there is any differences between the reference and the defect material for the test method NAW[®] which in that case would be an indicator that the test method could be useful for optimizing the production at the factory.

4.7 Acoustic Agree

Acoustic Agree is a company in Ronneby which offers to do nondestructive acoustical tests on a variety of materials and can also offer development of solutions to suit different customers. Mainly the work includes the method NAW[®], which is also industrially developed by the company. A lot of the equipment such as measurement tools and software is developed by the company and can be adapted for different kinds of problems. The company has been working on solutions for nonlinear acoustical material testing since 2006. [11]

5 Method

The way of carrying out this work contains four important steps; a literature study, experiments, analyzing data and summarizing results in a report. The literature study is essential for the understanding of acoustics in a nondestructive test situation. It will also serve as a toolbox to get useful information out of the data collected in the experiments. The experiments are the most time consuming part of this work and it is also the most important part considering gain of experience. The experimental setup, the method for the experiment and analyzing, NAW[®], and the procedure of analyzing the data is described in following subsections.

5.1 Experimental Setup

5.1.1 Preparation of samples

For this study material coming directly from the extruder in the lab of Tarkett is used. The material is pressed out of the machine in shape of approximately 1.5 m long bars of diameter, although the cross section is more oval than circular, up to 35 mm. The first thing done in our preparation is to cut the bars into to suitable pieces for the experiments. 150 mm was chosen as the length. Then piezoelectric transducers have to be attached to the ends of the samples. The way of attaching was chosen because the fact that the transducers are really small compared to the length of the material samples and due to the simplicity in the setup that will follow. Figure 5.1 and 5.2 shows how a prepared sample can look. Figure 5.3 shows the transducers used for the experiment. The big one is the transmitter with a diameter of 30 mm and the small one is the receiver with a diameter of 10 mm. The big transducer was chosen after trying out one small (as in figure 5.2) and one big. Of course the bigger one was more powerful and the signals became clearer. The transducers are all produced by Ferroperm Piezoceramics.

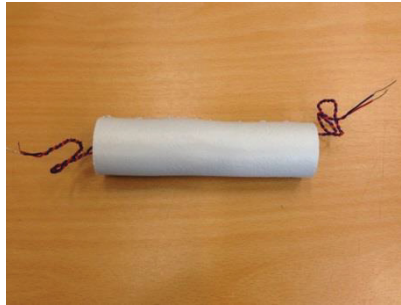


Figure 5.1. Sample prepared with transducers.

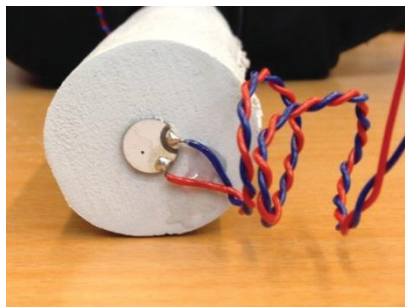


Figure 5.2. Sample prepared with transducers.

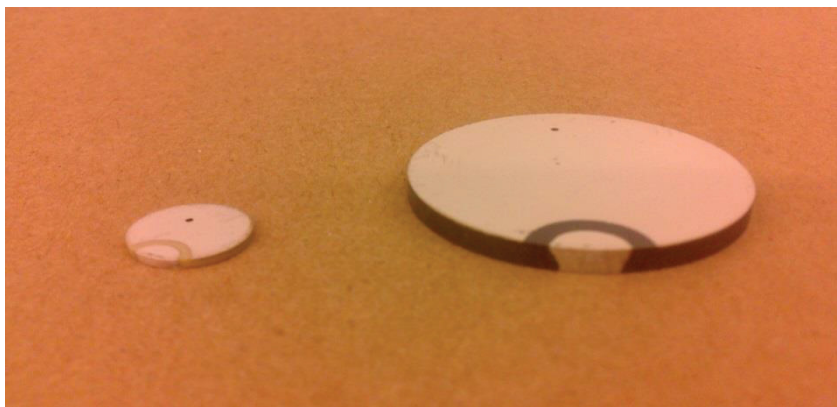


Figure 5.3. The transducers used for the experiments.

5.1.1.1 Defects

To imitate the real defects that occur in the production the 150 mm bars are cut in smaller parts and then glued together again with either air bubbles stirred into the glue for, Air void defect, or concentrations of particles of the material that has been extracted from the previous cutting, for Unmixed

Granulate defect. An example of the imitated Unmixed Granulate defect is shown in figure 5.4. It will not be the same as if the samples were already defect but it will hopefully give some hint of what the result will look like.



Figure 5.4. Introduction of Unmixed Granulate defect.

5.1.2 Test Setup

The equipment used is an Oscilloscope, a Signal Generator, an Amplifier and a Matching Transformer. Hanging the samples with fishing lines will make the boundaries similar to a free condition. Some of the equipment is shown in figure 5.5.



Fig 5.5. Amplifier, Matching Transformer and Signal Generator.

5.2 NAW[®]

The method or experimental technique used in this experiment is called NAW[®] short for Nonlinear Acoustical Wave modulation. In this method, the considered material is exposed to one high frequency from a signal generator and one or more low frequencies excited by either another signal generator or an impact hammer. The last case means that the material is hit by an impact hammer at the same time as the high frequency ultrasound is sent through it. It is possible to use other kinds of hammers or hitting devices too because the most important thing is that it is possible to see the frequency response from the material in question and not necessarily the signal from the hammer. The oscilloscope used in this experiment is advanced enough to show errors coming from overload impacts or hits not hard enough. The excitation waves are sent through the material using piezoelectric sensors, PZTs. The sensors transform voltage to mechanical waves, and mechanical waves to voltage, which means that a time domain signal of voltage changes is obtained.

The reason for this sort of excitation of the material is that if it contains any defects which cause nonlinear behavior of the sound waves it will show in the frequency response. A perfect material does not contain any nonlinearity at all but since there are in fact no perfect materials existing there will always be some amount of defects even if the sample of material is considered acceptable. In the ideal situation with a perfect material the frequencies put into the test sample will also be the frequencies coming out from the sample. In other words the input will be equal to the output of the system. If there are defects such as micro cracks in the sample the result is different. The sound wave will in this case be distorted while traveling through the material and passing the defects. This results in an output that is different from the input. [8] Another experimental technique that can be used to find nonlinearities is Higher Harmonics. For this only one input frequency is needed, but the most important thing is still to see how the output differs from the input for the damaged material. For a perfect material the input frequency is the only frequency showing in the output. For a damaged material harmonics will appear. The higher harmonics are multiples of the input frequency, which are showing due to the distortion of waves passing the damages. [8] Comparisons will be made to get as much information as possible regarding differences between reference and defect material. The comparisons are described in chapter 5.3 Result approach.

5.3 Result approach

To find potential patterns and indicators of defects a scheme for analyzing the collected data is followed. After following this scheme possible relations between the results can be concluded. Starting with a chosen frequency and voltage three samples for each defect type is treated. Then to see if that result is valid also if another frequency or voltage is used, one lower and one higher frequency as well as a higher voltage is analyzed.

1. Main frequency and main voltage. (Around 72 kHz and 10 V)
 - 1- Compare the area under the graph in the high peak area for reference and defect.
 - 2- Compare a damping ratio for the high frequency peak for reference and defect.
 - 3- How do the amplitudes change seen in reference and defect plots (from noise floor at the start of the high frequency peak area to the top of the peak)
 - 4- Compare Harmonics.
2. Decreased frequency. (Around 34 kHz and 10 V)
 - 1- Same as previous 1-4.
3. Increased frequency. (Around 124 kHz and 10 V)
 - 1- Same as previous 1-4.
4. Increased voltage. (Around 72 kHz and 30 V)
 - 1- Same as previous 1-4.

To choose which frequencies to use a frequency sweep has to be done. The sweep is carried out by continuously changing the frequency input to see which frequencies excite the material more or less. In this experiment a sweep was made for all of the samples, both reference and defect. Above the main frequency is said to be “around 72 kHz”. That is because the frequencies are a little different for each sample due to for example geometry, but the aim has been to choose correlating frequencies for all of the samples. An example of a sweep and the three chosen frequencies are shown in figure 5.6.

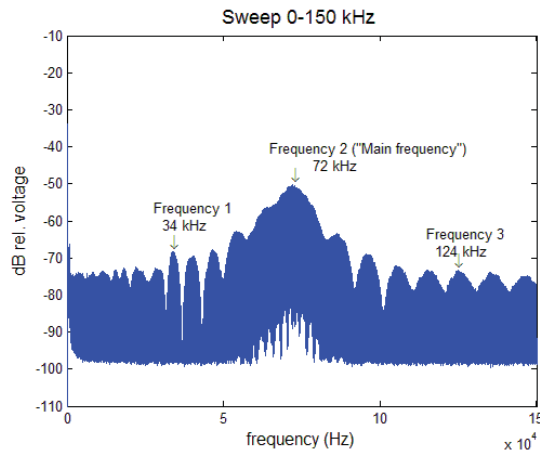


Figure 5.6. Example of frequency sweep from 0-150 kHz.

The material sample is then exposed to the chosen frequency coming from a signal generator and at the same time the impulse hammer is used to excite lower frequencies by tapping on the material. For every frequency 1-3, the tapping is made for a certain number of frequencies close around the chosen frequency, this to get a kind of average situation. The data from all those frequencies are then summarized to make it easier to interpret what is happening in the material when it is excited with frequencies around the peak in question. Such a summation is plotted in figure 5.7 for both reference and defective material.

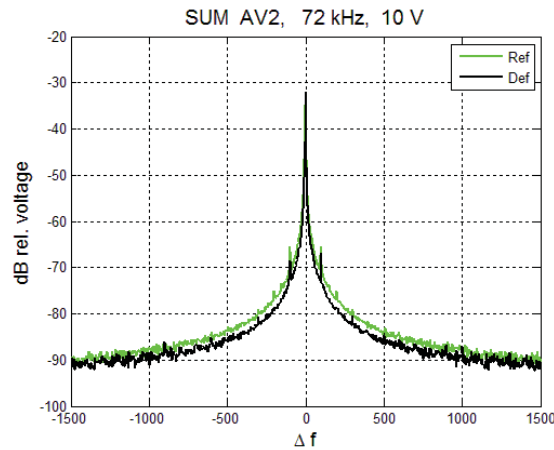


Figure 5.7. Example of summation for Air Voids sample 2 Reference (green) and Defect sample (black).

5.3.1 Area

By integrating the summations in figure 5.7 the area under the graphs are estimated. The integration is made very coarse simply by summing up the vector of amplitudes and multiplying by the frequency increment.

$$A \approx \sum y \cdot \Delta f \quad (5.1)$$

The difference in area in percent is then calculated in the following way.

$$Diff = \frac{A_{Ref} - A_{Def}}{A_{Ref}} \quad (5.2)$$

The using of equation 5.2 will result in a positive difference if the area is bigger for the reference than for the defect part. A negative difference therefore means that the area for the defect part instead is bigger than for the reference. The difference in area connected to the summations in figure 5.7 is shown in figure 5.8.

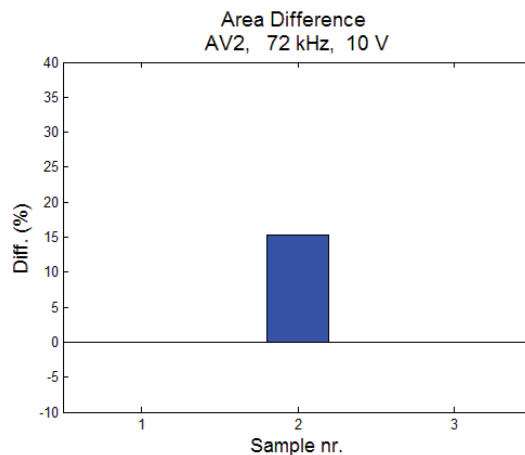


Figure 5.8. Example of Area Difference for Air Voids sample 2 where the area is bigger for the reference than for the defect part.

5.3.2 Relative Damping Ratio

The damping ratio is estimated directly from the power-spectrum received from the oscilloscope. The ratio ζ is estimated by using the 3 dB bandwidth or the half power bandwidth. The half power bandwidth B_r is calculated by finding the two frequencies f_u and f_l which has the amplitude which is half

of the amplitude of the peak at frequency f_d . [12] The ratio is calculated for all the averages around the chosen frequency and then divided into an average damping ratio.

$$B_r = f_u - f_l \quad (5.3) [12]$$

$$\zeta \approx \frac{B_r}{2f_d} \quad (5.4) [12]$$

5.3.3 Peak Amplitude

The peak amplitude is simply the magnitude of the peak of the summarized averages. It is noted in linear format and not in decibel for simplicity.

5.3.4 Harmonics

The harmonics should be found at multiples of the input frequency. Things happening around those frequencies can also be interesting, but there are also other disturbances which are not interesting for the result. To minimize those disturbances when interpreting the results the Harmonics are shown after subtracting the defect part from the reference part. In that way the common disturbances will partly disappear. Since the chosen frequency for the defect sample often is a little different from the frequency for the reference, all their harmonics will be shown in the plots which will make it easy to compare. If the chosen frequencies are the same for the reference and the defect the plots will still show the difference between the two parts which is what is interesting. In figure 5.9 the reference part and the defect part before the subtraction are shown. In the figure the placement of the Harmonics are also shown as H1 to H12 starting with H1 as the first harmonic after the input frequency. Other frequencies than the estimated harmonics will still be left after the subtraction and a validation for what can be important for the result or not will have to be done for every individual case. Figure 5.10 shows the result after subtracting the defect part from the reference, the format is there changed to linear. Just by looking at these two plots an opinion can be made about the differences between reference and defect material. If it looks like more harmonics has turned up, it can mean that more nonlinearity is present in the material. To see which of the peaks that are surely connected to the input frequency the peaks at the multiples of the input frequency are picked out and shown separately as in figure 5.11.

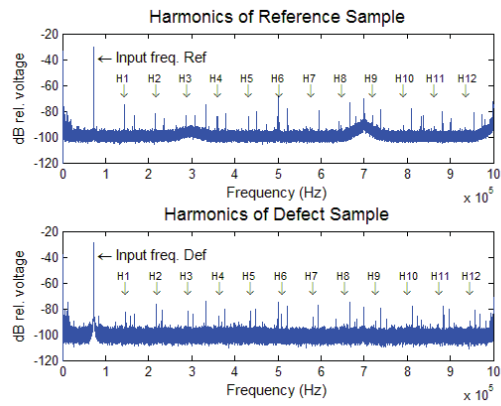


Figure 5.9. Example of harmonics plots for Reference (upper) and Defect sample (lower).

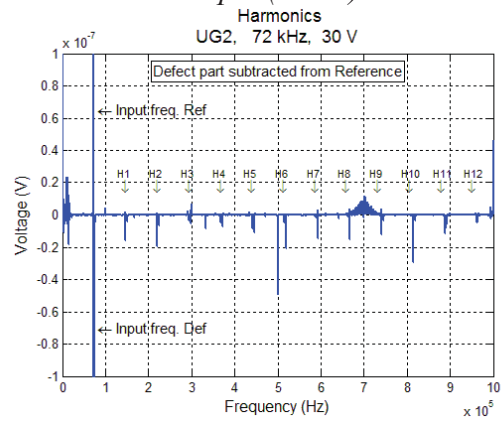


Figure 5.10. Example of a plot where the defect part's frequency response have been subtracted from the reference's response to show differences.

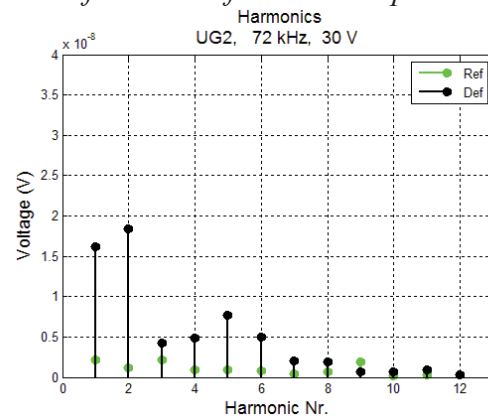


Figure 5.11. Example of picked out harmonics from reference (green) and defect part (black).

6 Results

The ideal result when analyzing the data from the experiments would be to find clear patterns of the differences between reference material and defect material. Although firstly the goal is to see if there are any differences to be found at all. If differences between reference material and the defect material appear the next step will be to find a way to connect them to the amount and type of defect. Each sample has its own reference and defect part as measurements were carried out on each sample before and after introducing defects.

6.1 Results for Unmixed Granulate

6.1.1 Main Frequency UG

Figure 6.1-3 is showing the summation made for all the samples and frequencies. It is from this collection of data all the following steps of the scheme is carried out. When the area is compared it is the area under the green and black curve shown in the figures respectively that is calculated.

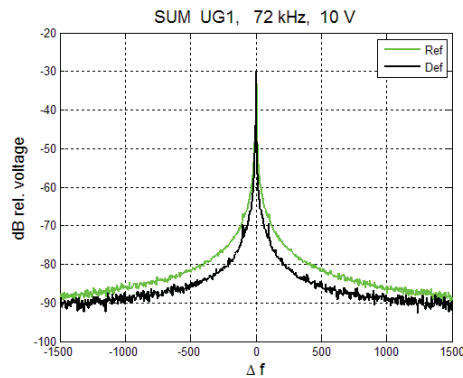


Figure 6.1. High input frequency peak for UG1, 72 kHz input frequency, 10 V driving amplitude, hit by hammer.

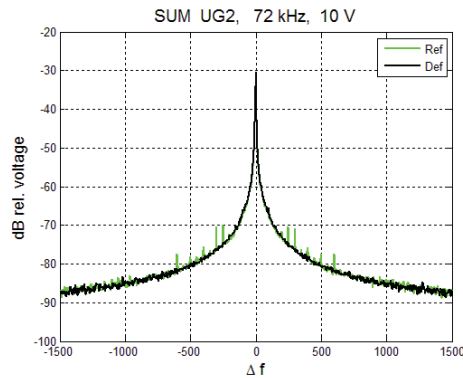


Figure 6.2. High input frequency peak for UG2, 72 kHz input frequency, 10 V driving amplitude, hit by hammer.

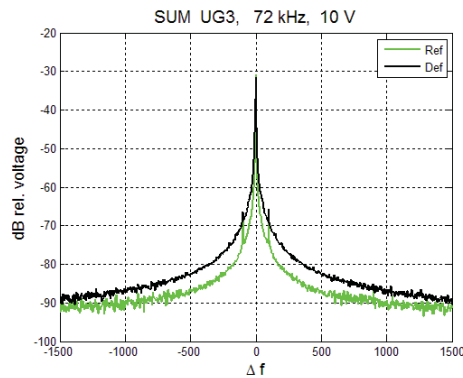


Figure 6.3. High input frequency peak for UG3, 72 kHz input frequency, 10 V driving amplitude, hit by hammer.

6.1.1.1 Area (Main frequency UG)

The three samples show different situations all three. (See figure 6.1 -6.3) First the reference is higher than the defect one, then for sample 2 they seem to be overlapping each other although the higher amplitude of the peak is causing a greater area for the defect; thirdly the reference is clearly under the defect curve. The calculated difference in percent is for UG1-3 respectively 10, -25 and -17 %. This means that the two samples with the highest amount of defects are showing a negative difference which is relatively high. The difference in percent and the calculated area are shown in figure 6.4 and 6.5.

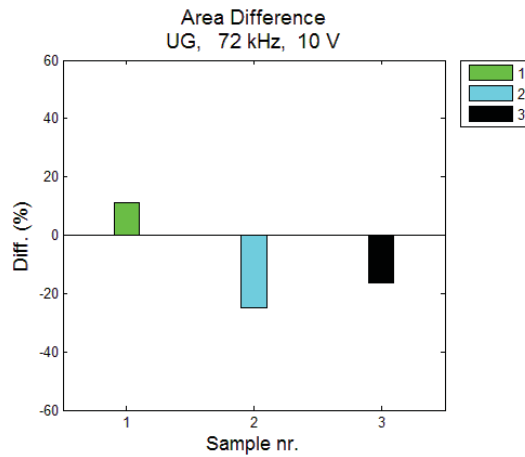


Figure 6.4. Area difference for UG, 72 kHz, 10 V.

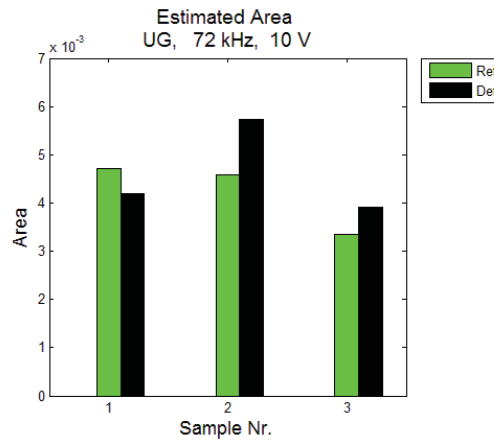


Figure 6.5. Estimated area for UG, 72 kHz, 10 V.

6.1.1.2 Damping (Main frequency UG)

In this case the calculated damping ratios, which are shown in figure 6.6 are clearly following the look of the peaks in figure 6.1-3 For UG 1 the reference peak is wider than the defect peak, which means higher damping for the reference and lower damping for the defect part. For UG 2 the damping is rather similar for the two peaks as the curves are almost overlapping each other. At last for UG 3 the ratio is lower for the reference since in this case it is the defect peak that is wider. The difference is calculated as 23.9, 2.6 and -32.2 % which shows rather a big difference between the samples. The difference between reference and defect part is compared to the reference

value of the damping, which means that compared with the reference the damping of UG3 has increased by 32.2 % for the defect part.

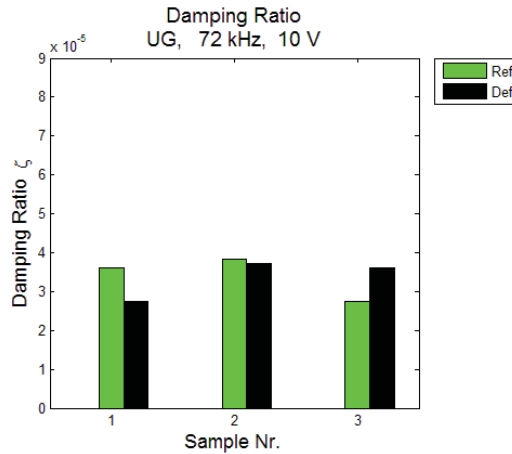


Figure 6.6. Damping Ratio estimated for UG, 72 kHz, 10 V.

6.1.1.3 Peak Amplitude (Main frequency UG)

The amplitudes of the peaks of the three samples are shown in figure 6.7. The peak amplitude is increasing from sample 1 to 3 for the references part and decreasing for the defect parts. For the first and second sample the amplitude is higher for the defect part.

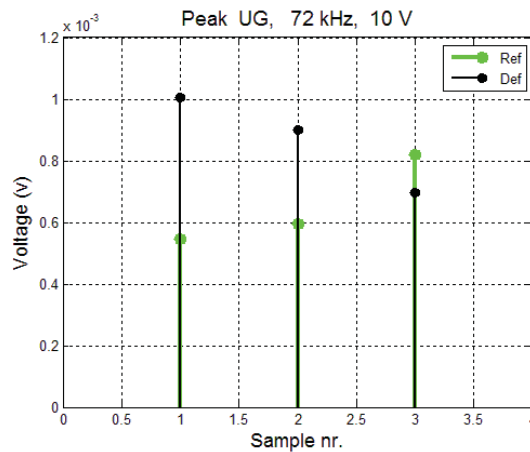


Figure 6.7. High frequency peak amplitude, 72 kHz, 10 V

6.1.1.4 Harmonics (Main frequency UG)

For 10 V there is not very many Harmonics represented at all. It mostly seems to be other disturbances. See figure 6.11 which shows an example of the harmonics from defect part subtracted from reference. What can be said is that the first Harmonic after the input frequency is present for all three samples. For sample one the harmonics are almost equal in amplitude for reference and defect part but for sample 2 and 3 the defect part contains much higher amplitude. Se figure 6.12-14

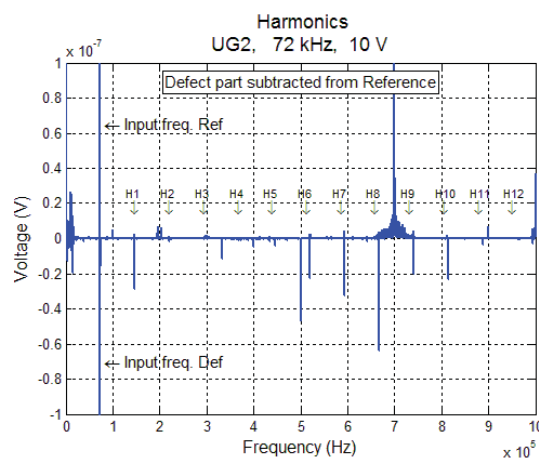


Figure 6.11. Harmonics from defect part subtracted from reference part UG2.

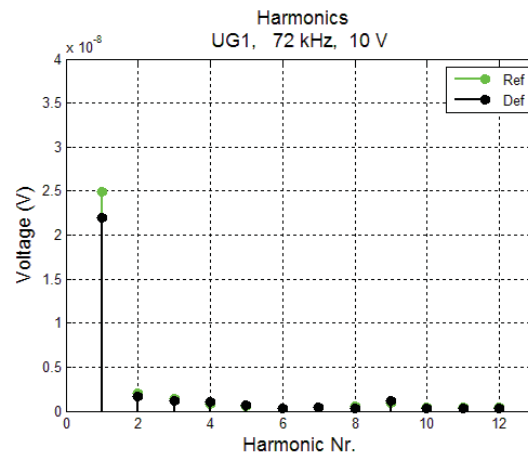


Figure 6.12. Harmonics picked out for UG1.

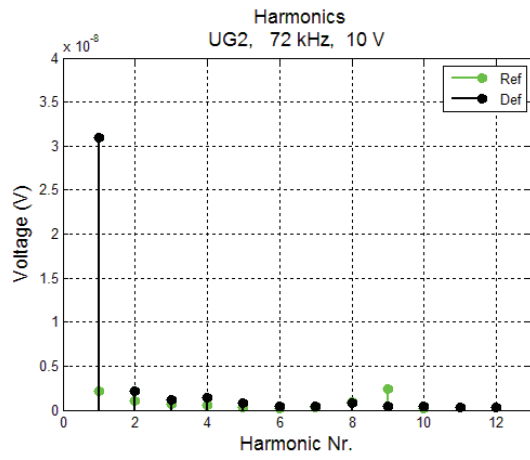


Figure 6.13. Harmonics picked out for UG2.

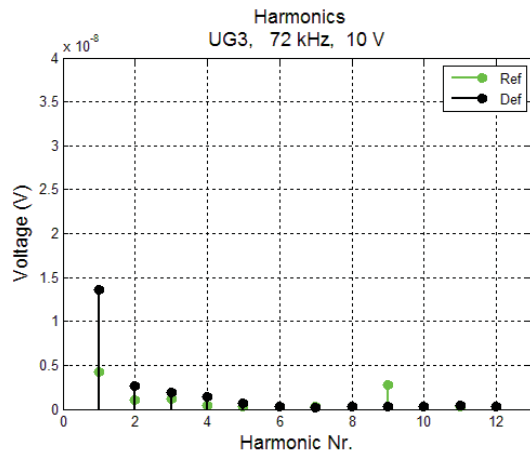


Figure 6.14. Harmonics picked out for UG3.

6.1.2 Decreased frequency

Figure 6.15-17 shows the frequency response around the peaks of 34 kHz.

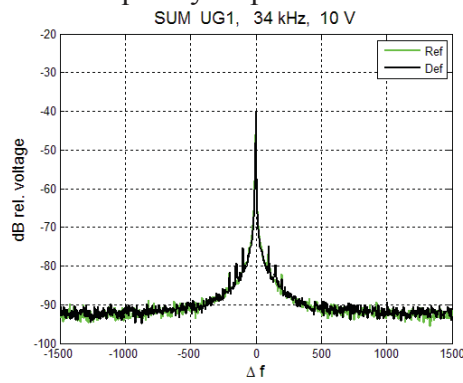


Figure 6.15. High frequency peak for UG1, 34 kHz input frequency, 10 V.

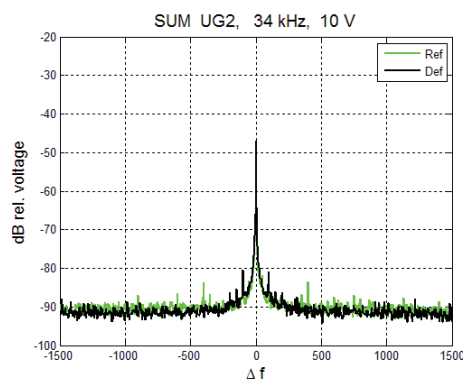


Figure 6.16. High frequency peak for UG2, 34 kHz input frequency, 10 V.

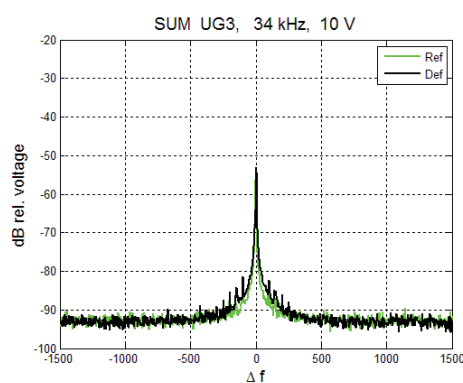


Figure 6.17. High frequency peak for UG3, 34 kHz input frequency, 10 V.

6.1.2.1 Area (Decreased frequency UG)

The difference in area and the area is presented in figure 6.18 and 6.19. In this case the area is bigger for the defect part in all samples. Even though the areas are differing for the different samples the difference in percent is rather similar for all of them. For UG1-3 the differences are -53, -43 and -53%. The numbers does not really insinuate which of the samples are the one with highest amount of defects, but at the same time it has to be noted that the areas for the references themselves are not similar to each other but decreasing a lot from UG1-3.

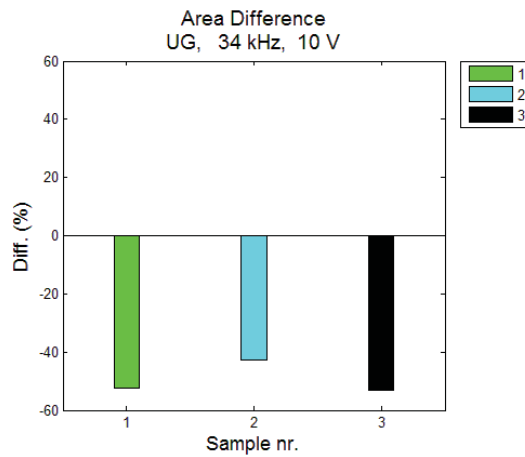


Figure 6.18. Area difference for UG, 34 kHz, 10 V.

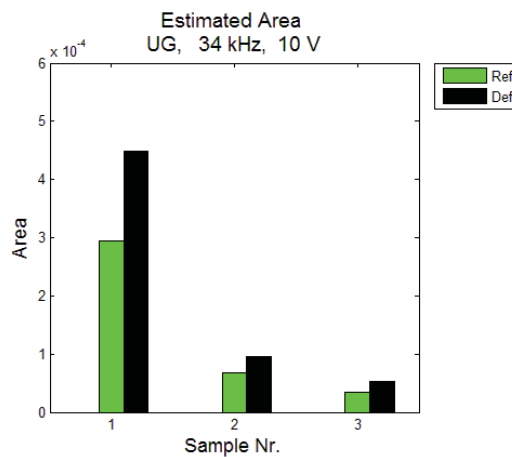


Figure 6.19. Estimated Area for UG, 34 kHz, 10 V.

6.1.2.2 Damping (Decreased frequency UG)

For this frequency it is harder to see simply by looking at the graphs which one of the reference and defect peak is more damped. The graphs seem to be overlapping each other and it cannot really be seen in figure 6.15-17 what is happening at the top of the peak, which is where the damping ratio is calculated. When studying figure 6.20 it can be seen that for the first sample UG1 the damping ratio is higher for the reference. For UG 2 the ratios are equal, and for UG 3 the ratio is higher for the defected part. The damping is increasing a lot for the most defect sample. The differences are calculated as 7.8, -0.2 and -21.4 %.

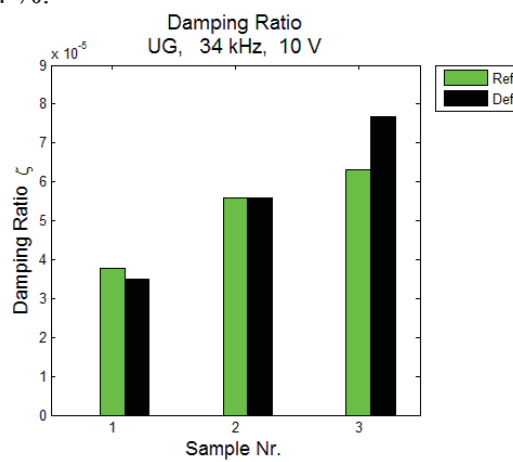


Figure 6.20. Damping Ratio estimated for UG, 34 kHz, 10 V.

6.1.2.3 Peak Amplitude

The amplitude of the peaks in figure 6.21 is decreasing from sample 1 to sample 3. The reference amplitude is always lower than the amplitude of the defect part.

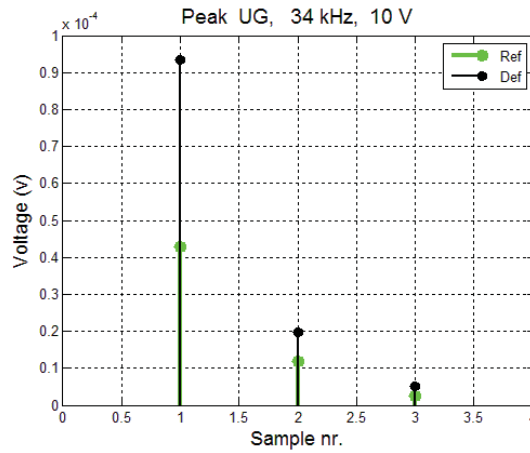


Figure 6.21. High frequency peak amplitude, UG, 34 kHz, 10 V.

The following table 6.1 shows an approximation of the amplitudes transitions in dB from main frequency 10 V to the decreased frequency. The noise floor amplitude and the peak amplitude in both obtained plots from the reference and defect materials are compared.

Table 6.1. Amplitude transitions by decreasing the main frequency

Sample	Starting point amp. app in both plots	The main frequency amp. app in both plots
1	$amp \approx -90 \rightarrow amp < -90$	$amp < -30 \rightarrow amp < -40$
2	$amp > -90 \rightarrow amp \cong -90$	$amp \approx -30 \rightarrow amp \approx -50$
3	$amp \approx -90 \rightarrow amp < -90$	$amp > -30 \rightarrow amp > -50$

6.1.2.4 Harmonics (Decreased frequency UG)

Since this frequency (34 kHz) does not excite the sample at all as much as the main frequency (72 kHz) the conditions are already worse to force harmonics to appear, figure 6.25 shows that this is the case. The harmonics shown in figure 6.26 are picked out at the multiples of the input frequency but are actually mostly part of the noise floor, meaning they have not really appeared. The result is mainly the same for all three samples.

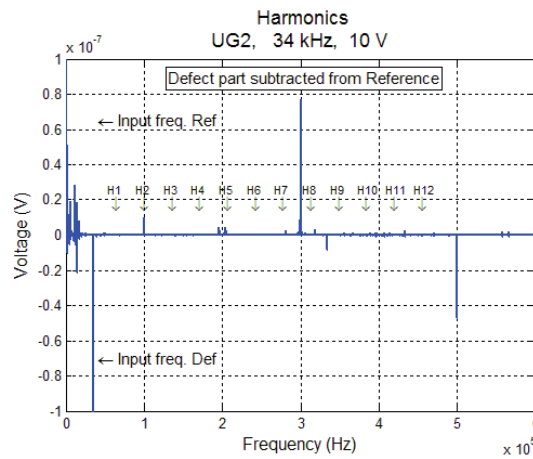


Figure 6.25. Harmonics from defect part subtracted from reference UG2.

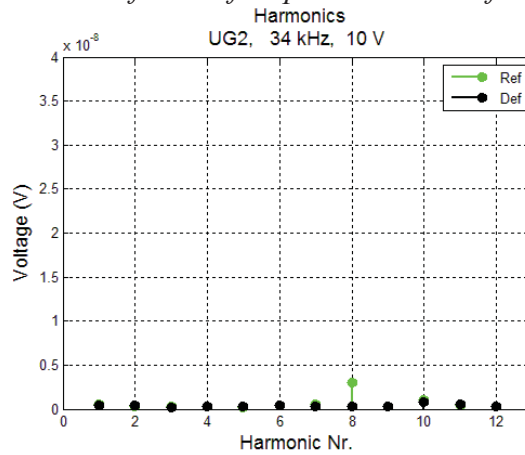


Figure 6.26. Harmonics picked out for UG2.

6.1.3 Increased Frequency

Figure 6.27-29 shows the frequency response around the peaks of 124 kHz.

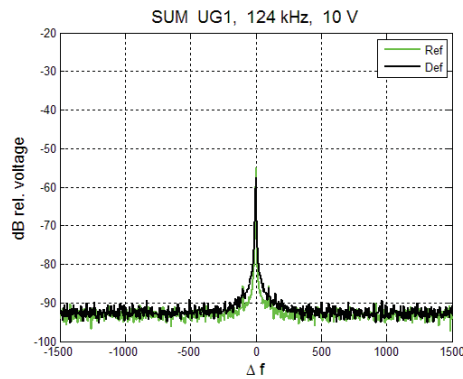


Figure 6.27. High frequency peak for UG1, 124 kHz, 10 V.

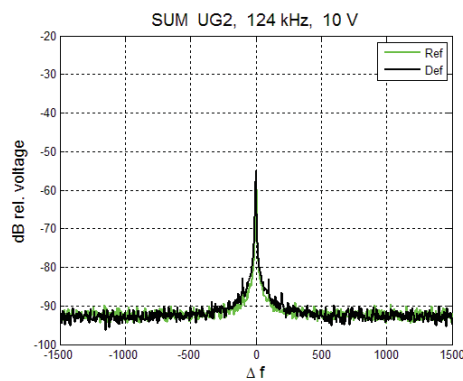


Figure 6.28. High frequency peak for UG2, 124 kHz, 10 V.

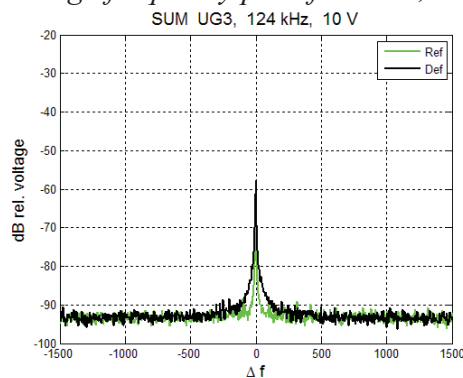


Figure 6.29. High frequency peak for UG3, 124 kHz, 10 V.

6.1.3.1 Area (Increased frequency UG)

In figure 6.30 and 6.31 the difference in area shows a similar pattern to the one for 72 kHz. UG1-3 shows a difference of 7, -27 and -27 %. Again as for 72 kHz the differences for the two samples with the highest amount of defects, UG2 and UG3, are negative and considerably higher than for UG1.

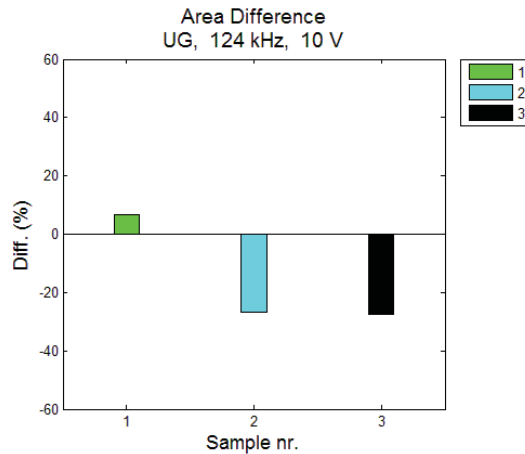


Figure 6.30. Area difference for UG, 124 kHz, 10 V.

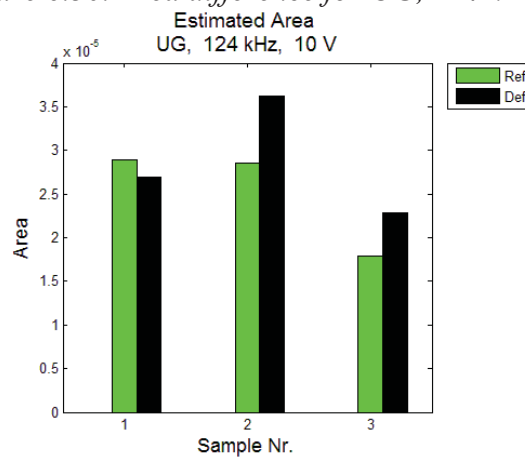


Figure 6.31. Estimated area for UG, 124 kHz, 10 V.

6.1.3.2 Damping (Increased frequency UG)

For the increased frequency 124 kHz all of the samples are showing a higher damping for the defect part. See figure 6.32. In figures 6.27-29 it is rather clear that this is the case since the defect black curve shows a little wider peak for all three samples. The pattern of the differences is not really indicating which one of the samples that contains the highest amount of damage but there is indeed difference between the reference and defect part. The differences in percent between reference and defect part are -41.9, -5.9 and -39.7 %. The results are as expected very similar to the result for the same frequency with driving voltage 10 V.

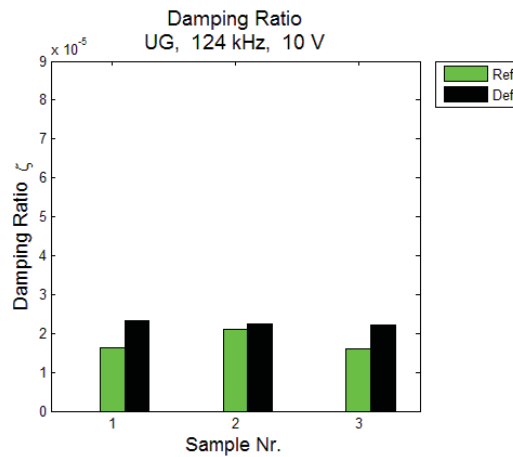


Figure 6.32. Damping Ratio estimated for UG, 124 kHz, 10 V.

6.1.3.3 Peak Amplitude (Increased frequency UG)

The first sample shows higher amplitude for the reference while for sample 2 and 3 it is the other way around. See figure 6.33.

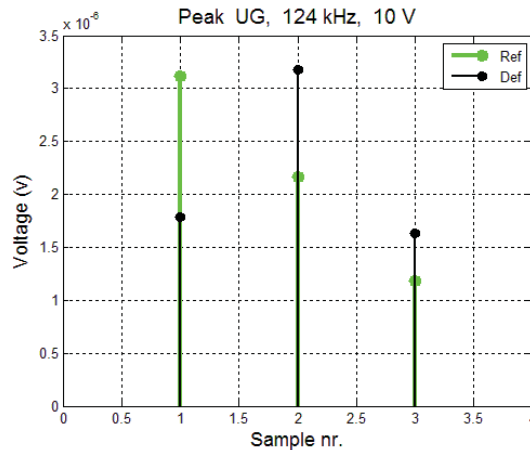


Figure 6.33. High frequency peak amplitude UG, 124 kHz, 10 V.

The following table 6.2 shows an approximation of the amplitudes transitions in dB from main frequency 10 V to the increased frequency. The noise floor amplitude and the peak amplitude in both obtained plots from the reference and defect materials are compared.

Table 6.2. Amplitudes transitions by increasing the main frequency

Sample	Starting point amp. app in both plots	The main frequency amp. app in both plots
1	$amp \approx -90 \rightarrow amp < -90$	$amp < -30 \rightarrow amp \approx -55$
2	$amp > -90 \rightarrow amp < -90$	$amp \approx -30 \rightarrow amp \approx -55$
3	$amp \approx -90 \rightarrow amp < -90$	$amp > -30 \rightarrow amp > -60$

6.1.3.4 Harmonics (Increased frequency UG)

The same as for the lower frequency (34 kHz) is happening for the higher on (124 kHz). The harmonics are mostly just buried in the noise floor and cannot really be considered as noticeable. The data is shown in figure 6.37 and 6.38. The result is mainly the same for all three samples.

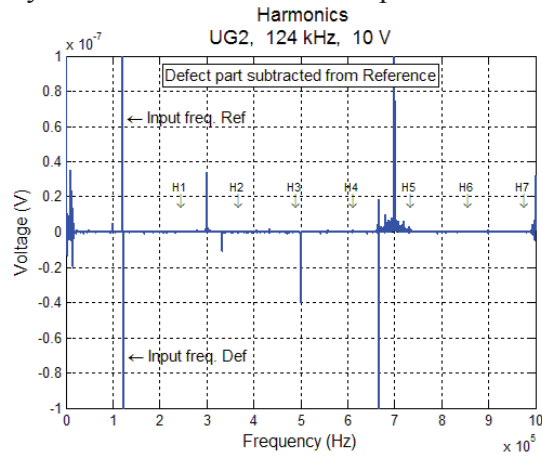


Figure 6.37. Harmonics from defect part subtracted from reference part, UG2.

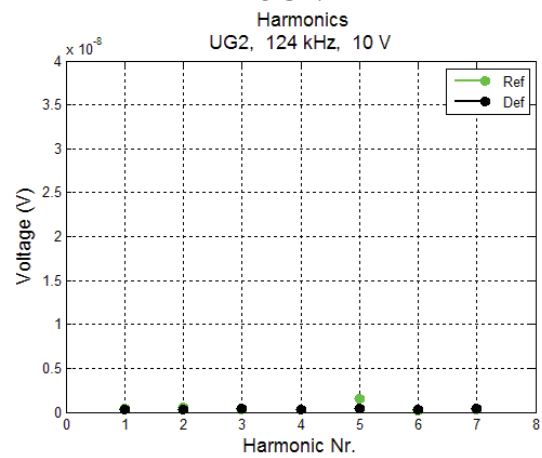


Figure 6.38. Harmonics picked out for UG1.

6.1.4 Increased Voltage

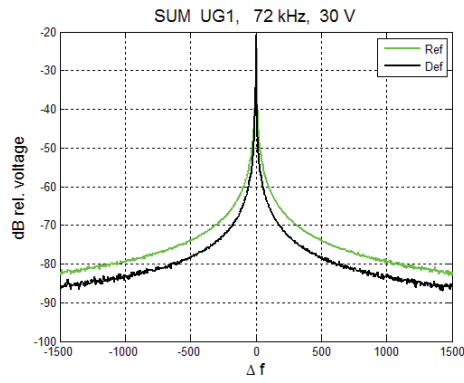


Figure 6.39. High frequency peak for UG1, 72 kHz, 30 V.

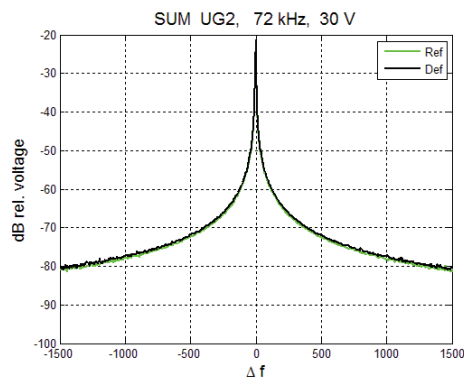


Figure 6.40. High frequency peak for UG2, 72 kHz, 30 V.

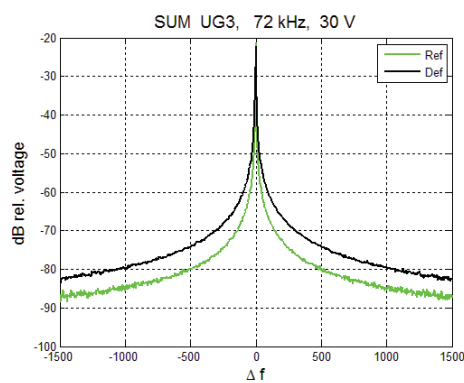


Figure 6.41. High frequency peak for UG3, 72 kHz, 30 V.

6.1.4.1 Area (Increased voltage UG)

In the same way as for 72 kHz 10 V the areas reflect what is seen in figures 6.39-41. Except for UG 2 which is once again showing quite a big difference in figure 6.42 and 6.43 that cannot be seen that simply in figure 6.40 The pattern is the same as for 10 V and the differences for UG1-3 are 3, -21 and 14 %. Again the two samples with most defects are showing big negative difference.

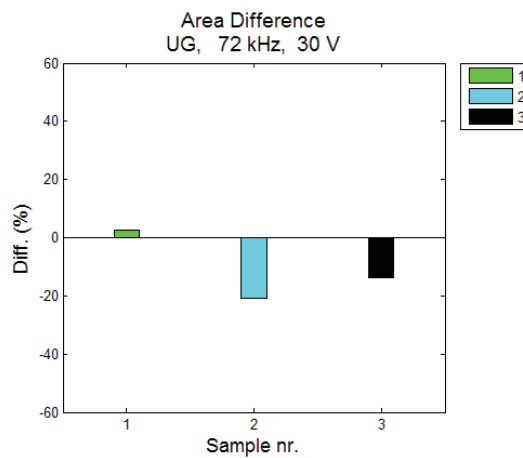


Figure 6.42. Area difference for UG, 72 kHz, 30V.

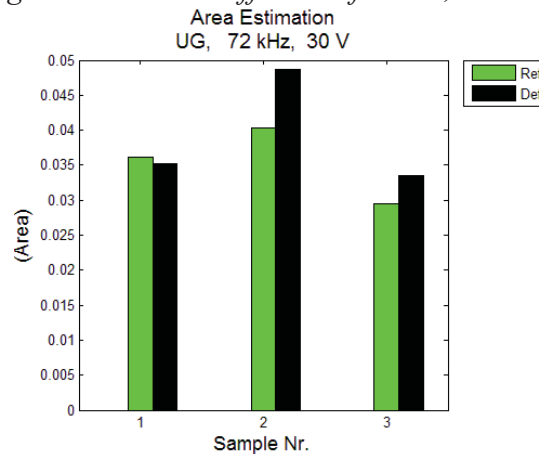


Figure 6.43. Estimated area for UG, 72 kHz, 30 V.

6.1.4.2 Damping (Increased voltage UG)

The damping ratios for 72 kHz 30 V shown in figure 6.44 are almost equal to the ratios for 10 V, which is expected since the plots in figure 6.39-41 are similar to the plots for 10 V in figure 6.1-6.3 and the only parameter change is the increased driving voltage. The damping goes from being considerably lower for the defect UG1 to be higher for the defect version UG3. The differences UG1-3 are 23.3, 2.3 and -32.4 %.

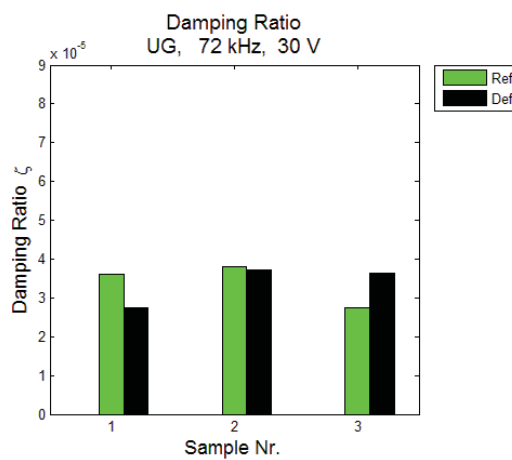


Figure 6.44. Damping Ratio estimated for UG, 72 kHz, 30 V.

6.1.4.3 Peak Amplitude (Increased voltage UG)

The peak amplitude is increasing from sample 1 to 3 for the references part and decreasing for the defect parts. For the first and second sample the amplitude is higher for the defect. The pattern is the same as for 10 V. See figure 6.45.

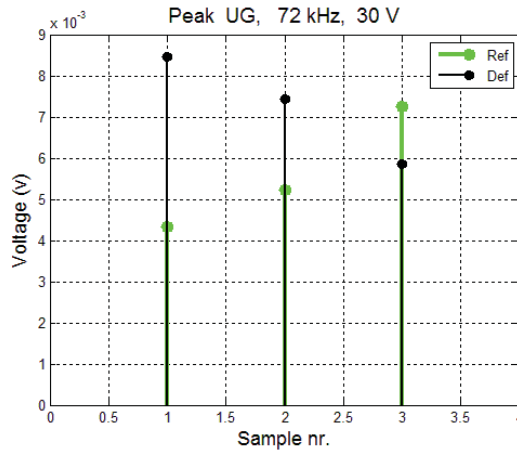


Figure 6.45. High frequency peak amplitude UG, 72 kHz, 30 V.

The following table 6.3 shows an approximation of the amplitudes transitions in dB from main frequency 10 V to the increased voltage. The noise floor amplitude and the peak amplitude in both obtained plots from the reference and defect materials are compared. However the amplitudes increase can be an obvious outcome of increasing the voltage.

Table 6.3. Amplitudes transitions by increasing the main voltage

Sample	Starting point amp. app in both plots	The main frequency amp. app in both plots
1	$amp \approx -90 \rightarrow -80 < amp < -90$	$amp > -30 \rightarrow amp < -20$
2	$amp > -90 \rightarrow amp \approx -80$	$amp \approx -30 \rightarrow amp \approx -25$
3	$amp \approx -90 \rightarrow -80 < amp < -90$	$amp < -30 \rightarrow amp \approx -25$

6.1.4.4 Harmonics (Increased voltage UG)

By using the driving voltage 30 V, the some harmonics finally appear. Among with a lot of other combinations of frequencies which are often even bigger than the harmonics themselves, see figure 6.49. Still the harmonics are possible to pick out and are shown in figure 6.50-52. The result for reference versus defect is shifting forms a little for the different samples but mostly the defect part is showing harmonics of higher amplitude than the reference.

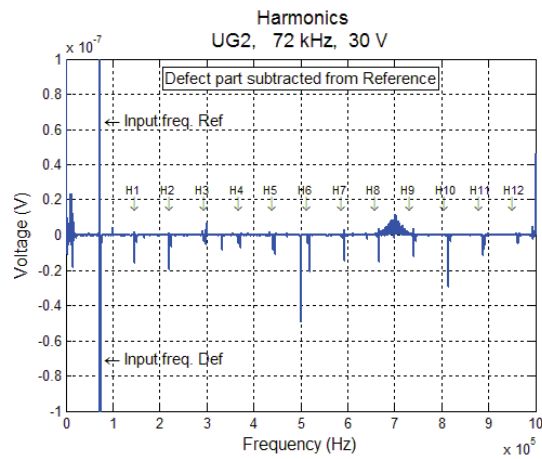


Figure 6.49. Harmonics from defect part subtracted from reference part, UG.

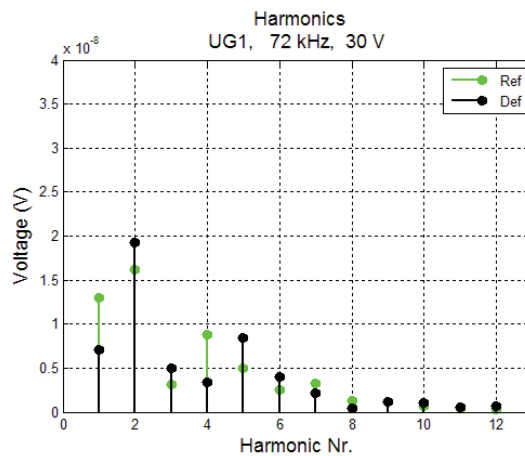


Figure 6.50. Harmonics picked out for UG1.

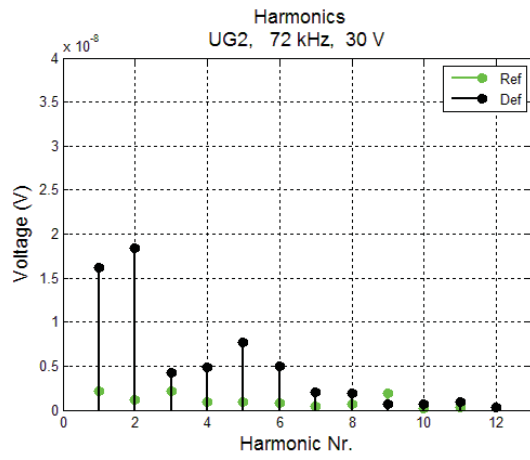


Figure 6.51. Harmonics picked out for UG2.

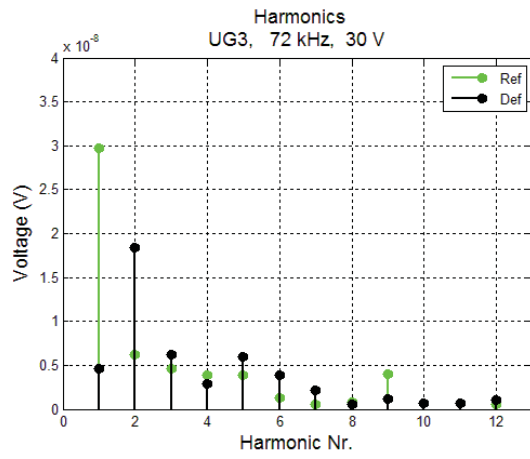


Figure 6.52. Harmonics picked out for UG3.

6.1.5 Conclusion Unmixed Granulate

The results from the Unmixed Defect are briefly summarized in four tables below, table 6.4-7. First, we are supposed to see if the properties in question has increased or decreased for the defect material compared to the reference, which are shown in the mentioned tables. The numbers of the values are varying a lot, even for the reference material and therefore the conclusion is mostly looking at the difference between reference and defect part of each individual sample.

Table 6.4. Table indicating if the property in question has increased or decreased after defect introduction. For UG, 72 kHz, 10 V.

Defect material properties in relation to Reference material properties			
72 kHz, 10 V	UG 1	UG 2	UG 3
Area	-	+	+
Damping ratio	-	=	+
Peak Amplitude	+	+	-
Harmonics Amplitude	-	+	+
Harmonics Nr.	=	=	=

Table 6.5. Table indicating if the property in question has increased or decreased after defect introduction. For UG, 34 kHz, 10 V.

Defect material properties in relation to Reference material properties			
34 kHz, 10 V	UG 1	UG 2	UG 3
Area	+	+	+
Damping ratio	-	=	+
Peak Amplitude	+	+	+
Harmonics Amplitude	=	=	=
Harmonics Nr.	=	=	=

Table 6.6. Table indicating if the property in question has increased or decreased after defect introduction. For UG, 124 kHz, 10 V.

Defect material properties in relation to Reference material properties			
124 kHz, 10 V	UG 1	UG 2	UG 3
Area	-	+	+
Damping ratio	+	+	+
Peak Amplitude	-	+	+
Harmonics Amplitude	=	=	=
Harmonics Nr.	=	=	=

Table 6.7. Table indicating if the property in question has increased or decreased after defect introduction. For UG, 72 kHz, 30 V.

Defect material properties in relation to Reference material properties			
72 kHz, 30 V	UG 1	UG 2	UG 3
Area	-	+	+
Damping ratio	-	-	+
Peak Amplitude	+	+	-
Harmonics Amplitude	+/-	+	+/-
Harmonics Nr.	=	+	=

The common behavior is that the properties mostly increase for the defect samples. Some exceptions exist but it seems as if the more defects introduced to the material the more certain is the fact that the properties will have increased. For example for 72 kHz, 10 V, the properties are mostly decreasing for UG1 but for UG 2 and 3 almost all the properties have been increased for the defect sample. The pattern of increasing properties is happening also for 34 and 124 kHz. For 72 kHz, 30 V are very similar to the ones for 10 V, except the harmonics which are increasing a lot with the voltage.

The harmonics are only really interesting for 30 V, since there are almost no harmonics showing for lower driving voltage. For 30 V the amplitudes are going towards higher magnitude even though there are exceptions.

6.2 Results for Air voids

6.2.1 Main Frequency

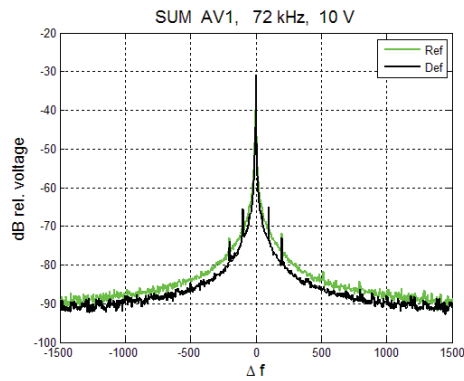


Figure 6.53. High frequency peak for AV1, 72 kHz, 10V.

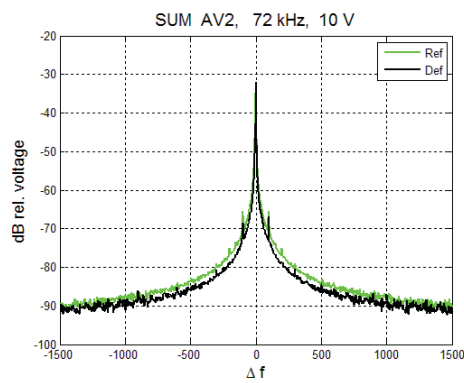


Figure 6.54. High frequency peak for AV2, 72 kHz, 10V.

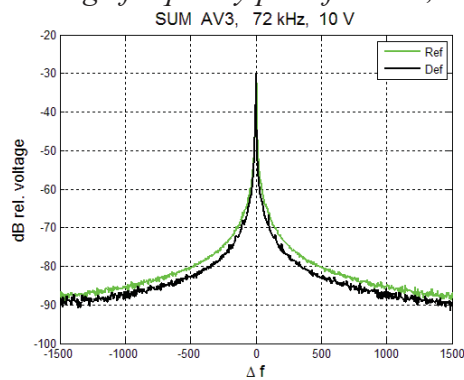


Figure 6.55. High frequency peak for AV3, 72 kHz, 10V.

6.2.1.1 Area (Main frequency AV)

The areas for the reference and the defect part are shown in figure 6.56 and 6.57. It is indicating that the reference area is greater than the defect for both AV 2 and 3. When studying the plots in figures 6.53-55 it seems that all the samples should show such a result. Once again it is probably due to what is happening at the top of the peak which cannot really be seen as simply in the decibel plots. The area difference is for AV1-3 respectively -16, 15 and 19 %.

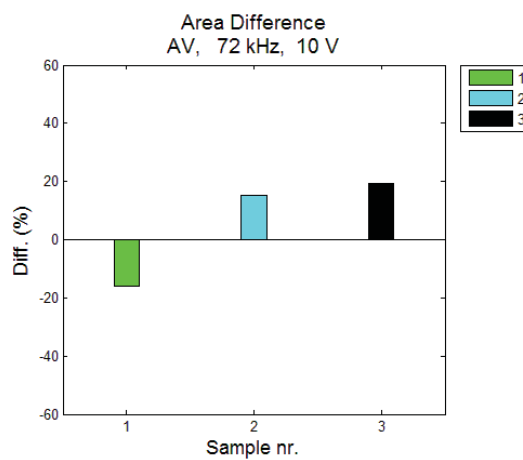


Figure 6.56. Area difference for AV, 72 kHz, 10 V.

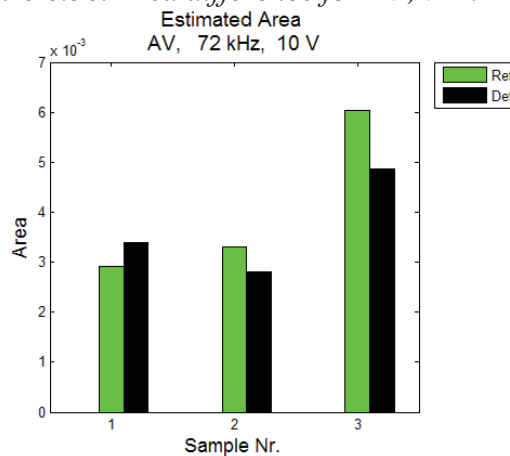


Figure 6.57. Estimated area for AV, 72 kHz, 10 V.

6.2.1.2 Damping (Main frequency AV)

The damping ratios, see figure 6.58, are greater for the reference in all samples, and overall the ratios are relatively similar for all the samples. This is also easy to see in figures 6.53-55 since the green reference peak is slightly wider than the defect black peak. The references damping are rather similar for all three samples. The difference between reference and defect part are from AV 1 to 3 respectively 15, 10.6 and 13 %. In other words AV 3 has a damping ratio 13% lower for the defect compared to the reference part.

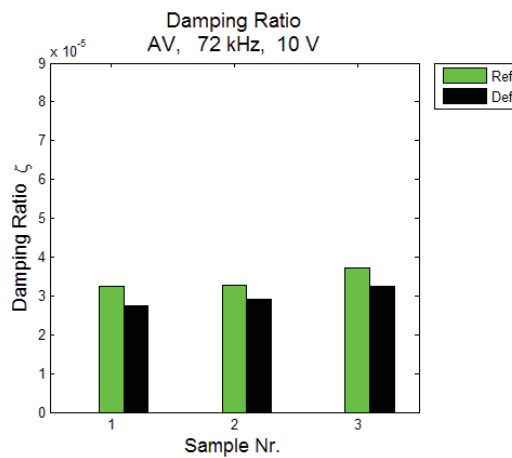


Figure 6.58. Damping Ratio estimated for AV, 72 kHz, 10 V.

6.2.1.3 Peak Amplitude (Main frequency AV)

The amplitudes in figure 6.59 are different for all samples but always higher for the defect part. The difference between reference and defect part is similar for all three samples.

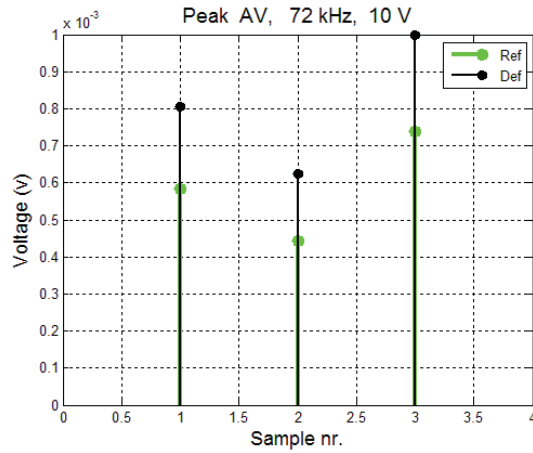


Figure 6.59. High frequency peak amplitude AV, 72 kHz, 10 V.

6.2.1.4 Harmonics (Main frequency AV)

Once again for 10 V there is not many harmonics showing (see figure 6.63), but the ones that are showing are rather similar in reference and defect part. See figure 6.64-66.

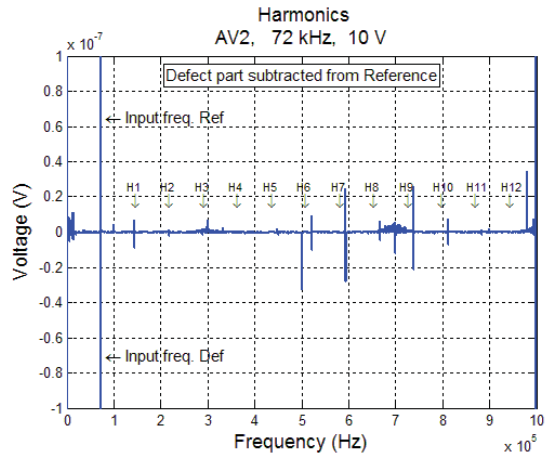


Figure 6.63. Harmonics for defect part subtracted from reference part, AV2.

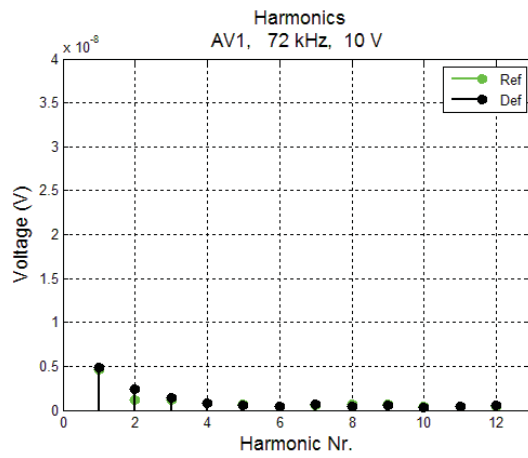


Figure 6.64. Harmonics picked out for AV1.

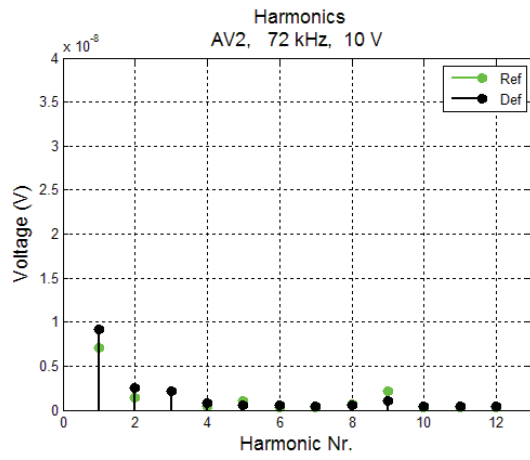


Figure 6.65. Harmonics picked out for AV2.

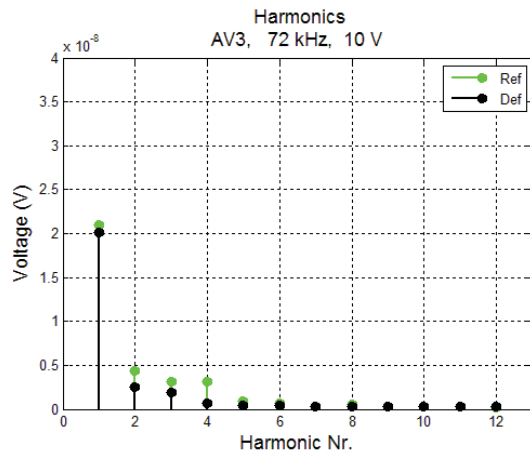


Figure 6.66. Harmonics picked out for AV3.

6.2.2 Decreased Frequency

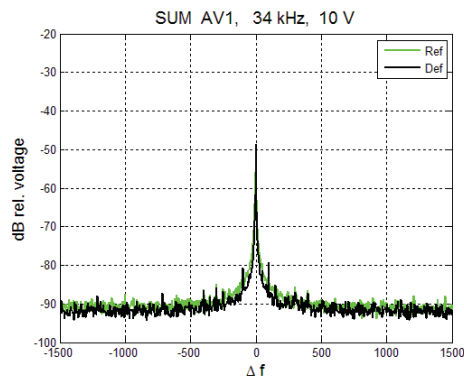


Figure 6.67. High frequency peak for AV1, 34 kHz, 10 V.

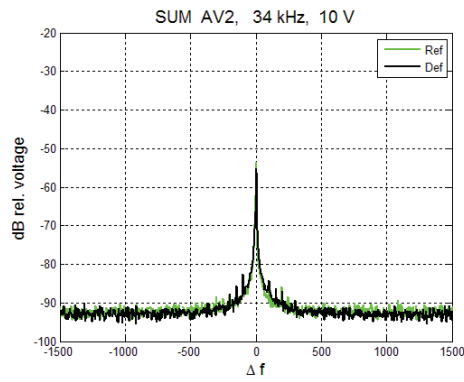


Figure 6.68. High frequency peak for AV2, 34 kHz, 10 V.

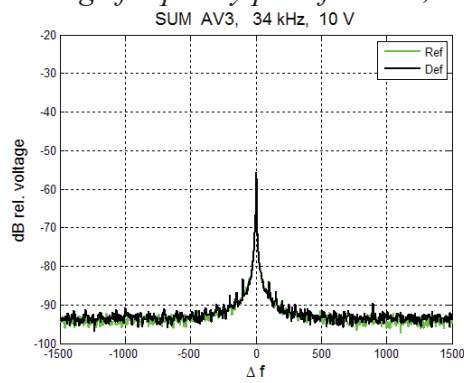


Figure 6.69. High frequency peak for AV3, 34 kHz, 10 V.

6.2.2.1 Area (Decreased frequency AV)

All the area differences in figure 6.70 and 6.71 are rather small but for AV3 it is however clear. The differences for AV 1-3 are 0.3, -2 and -14 %. For the sample which is exposed to the highest amount of defects the difference is negative and much higher than for the other two samples.

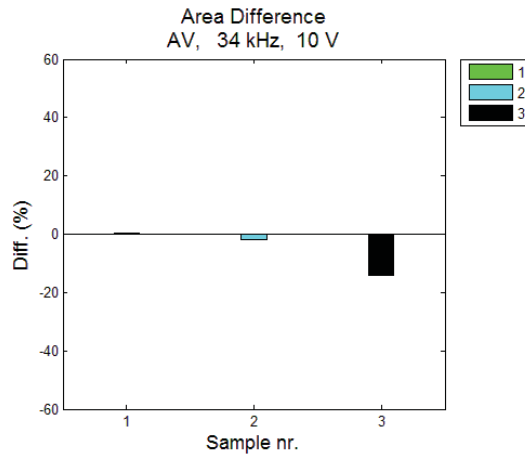


Figure 6.70 Area difference for AV, 34 kHz, 10 V.

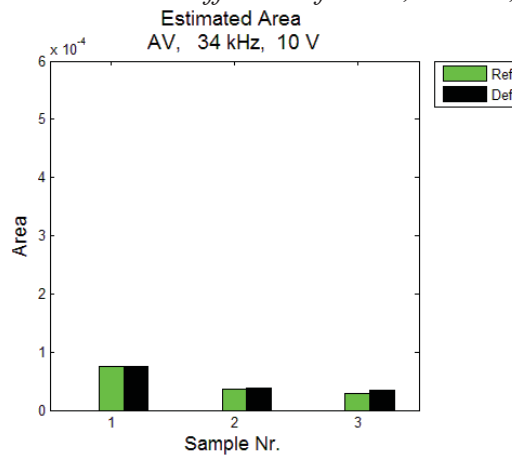


Figure 6.71. Estimated area for AV, 34 kHz, 10 V.

6.2.2.2 Damping (Decreased frequency AV)

For this frequency, 34 kHz, the first sample AV 1 shows the biggest difference in damping ratio, the reference has here clearly a higher ratio. The ratios for sample 2 and 3 are almost equal, although a little higher for the defect parts, see figure 6.72. In this case the references show similar results for all three samples. The differences are 26, -1.3 and -0.8 %.

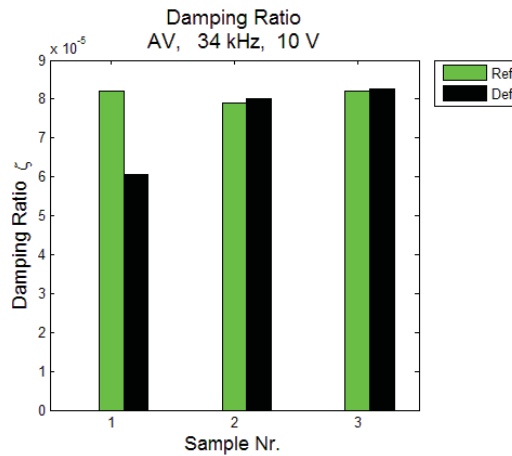


Figure 6.72. Damping ratio estimated for AV, 34 kHz, 10 V.

6.2.2.3 Peak Amplitude (Decreased frequency AV)

The amplitudes are generally decreasing from sample 1 to 3. For sample 1 and 3 the defect samples show higher peak amplitudes than the references. For sample 2 it is the other way around. See figure 6.73.

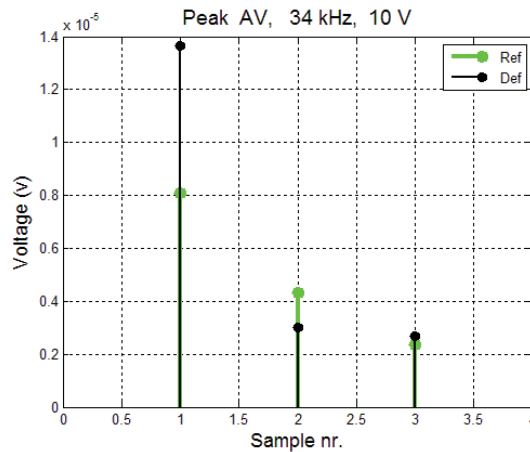


Figure 6.73. High frequency peak amplitude AV, 34 kHz, 10 V.

The following table 6.8 shows an approximation of the amplitudes transitions in dB from main frequency 10 V to the decreased frequency. The noise floor amplitude and the peak amplitude in both obtained plots from the reference and defect materials are compared.

Table 6.8. Amplitudes transitions by decreasing the main frequency

Sample	Starting point amp. app in both plots	The main frequency amp. app in both plots
1	$amp \approx -90 \rightarrow amp < -90$	$amp < -30 \rightarrow amp < -50$
2	$amp = -90 \rightarrow amp < -90$	$amp < -30 \rightarrow amp \approx -55$
3	$amp > -90 \rightarrow amp \approx -90$	$amp < -30 \rightarrow amp < -55$

6.2.2.4 Harmonics (Decreased frequency AV)

As can be seen in figure 6.77 and 6.78 and there are only three harmonics and two of them really stands out and the amplitude is much higher than for the rest of the harmonics. Unfortunately the reason for this is that they are more probable to be connected with some other disturbance than the material property itself. Otherwise the harmonics is hardly even showing.

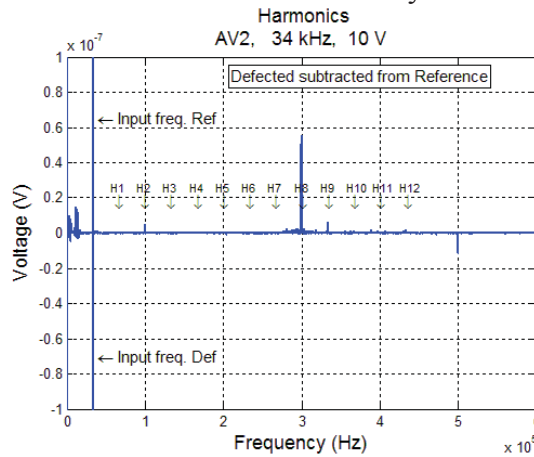


Figure 6.77. Harmonics from defect part subtracted from reference, AV1.

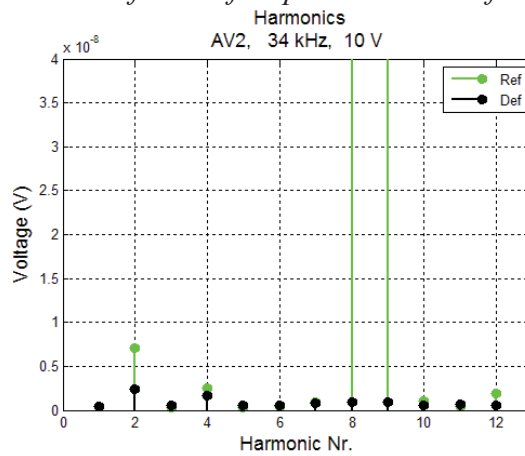


Figure 6.78. Harmonics picked out for AV1.

6.2.3 Increased Frequency

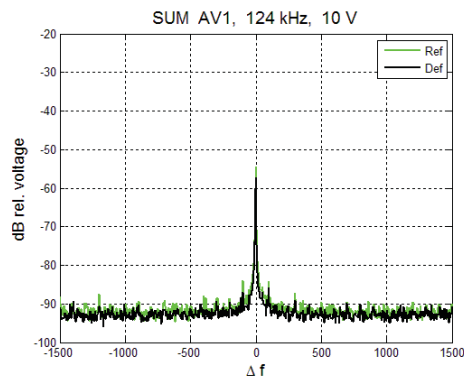


Figure 6.79 High frequency peak for AV1, 124 kHz, 10 V.

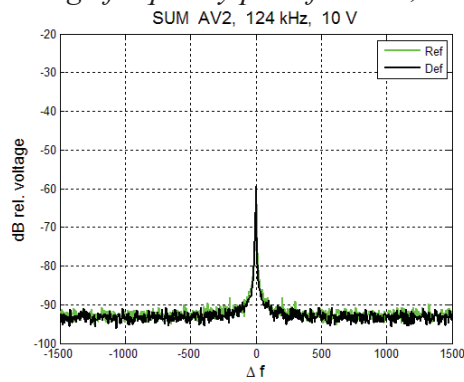


Figure 6.80. High frequency peak for AV2, 124 kHz, 10 V.

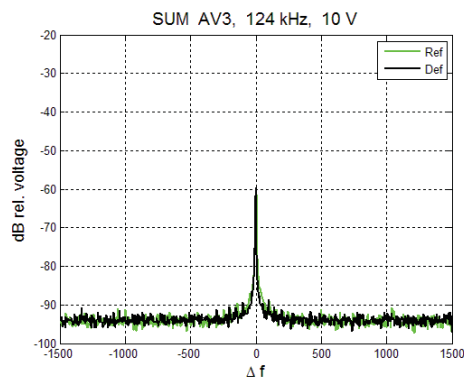


Figure 6.81. High frequency peak for AV3, 124 kHz, 10 V.

6.2.3.1 Area (Increased frequency AV)

For all samples the reference area is greater than the defect area. The areas are decreasing from AV 1-3 as 23, 8 and 1 %. See figure 6.82. Also here there is a considerable difference already between the references which is clear in figure 6.83.

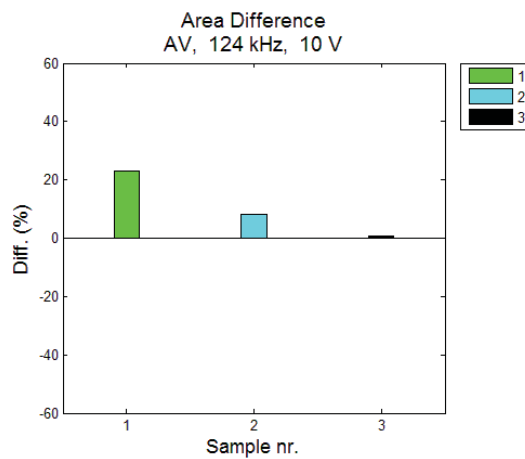


Figure 6.82. Area difference for AV1, 124 kHz, 10 V.

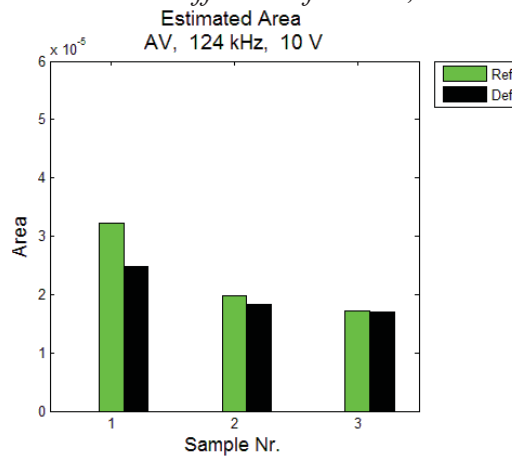


Figure 6.83. Estimated area for AV1, 124 kHz, 10 V.

6.2.3.2 Damping (Increased frequency AV)

By studying the plots in figure 6.79-81 it seems as if the damping for all the peaks is almost equal since the curves pretty much overlap each other. Figure 6.84 confirms it, the ratios are very similar but the reference always holds a ratio that is a little higher than the defect part. The difference for AV1-3 respectively is 2.9, 10, 11 %.

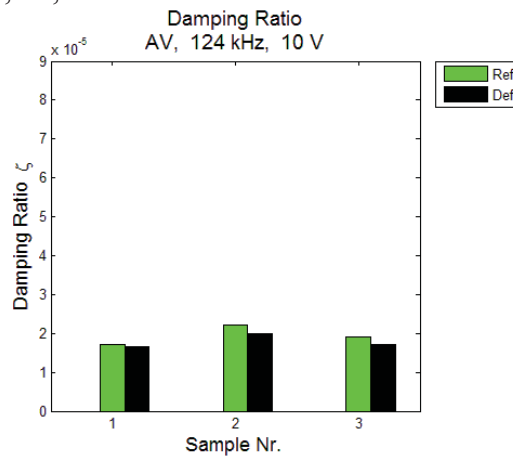


Figure 6.84. Damping Ratio for AV1, 124 kHz, 10 V.

6.2.3.3 Peak Amplitude (Increased frequency AV)

Sample AV1 shows quite a big difference in amplitude between reference and defect sample. It also has much higher amplitude than the other two samples. For AV 2 and 3 the peak amplitude is a little higher for the defect part. This is clearly visible in figure 6.85.

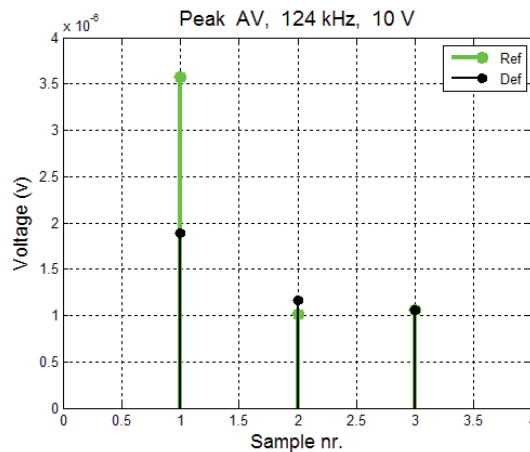


Figure 6.85. High frequency peak amplitude AV, 124 kHz, 10 V.

The following table 6.9 shows an approximation of the amplitudes transitions in dB from main frequency 10 V to the increased frequency. The noise floor amplitude and the peak amplitude in both obtained plots from the reference and defect materials are compared.

Table 6.9. Amplitudes transitions by increasing the main frequency

Sample	Starting point amp. app in both plots	The main frequency amp. app in both plots
1	$amp \approx -90 \rightarrow amp < -90$	$amp < -30 \rightarrow amp < -55$
2	$amp = -90 \rightarrow amp < -90$	$amp < -30 \rightarrow amp \cong -60$
3	$amp > -90 \rightarrow amp \approx -95$	$amp < -30 \rightarrow amp \cong -60$

6.2.3.4 Harmonics (Increased frequency AV)

In figure 6.89 and 6.90 no harmonics are showing, but still at some places there are high peaks. The driving voltage 10 V is probably too low to excite the sample and material itself.

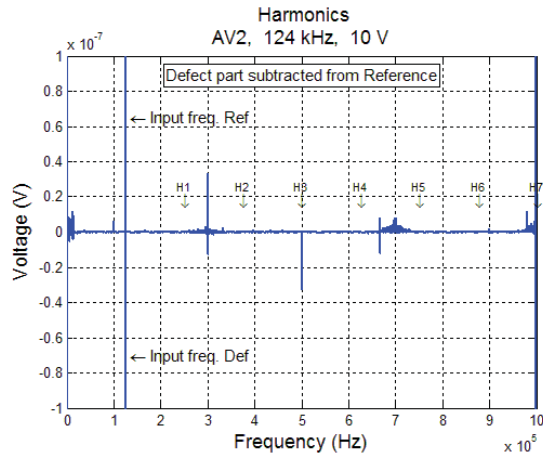


Figure 6.89. Harmonics from defect part subtracted from reference part. AV2.

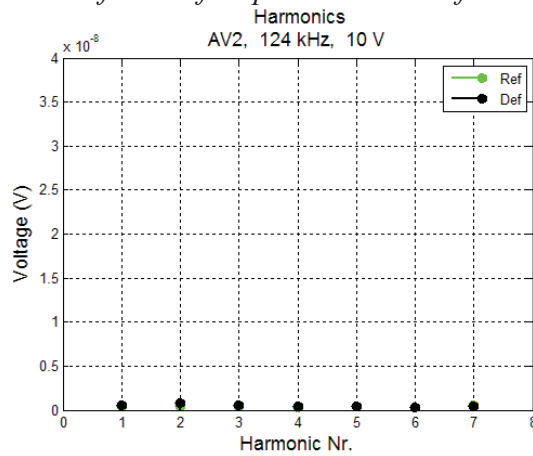


Figure 6.90. Harmonics picked out for AV2.

6.2.4 Increased Voltage

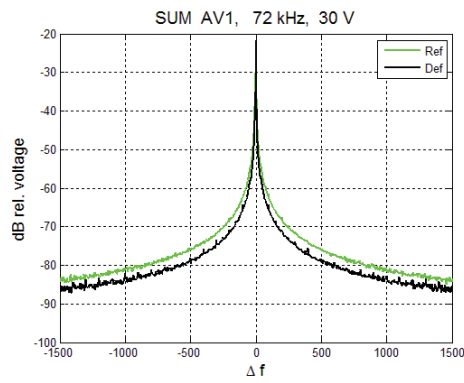


Figure 6.91. High frequency peak for AV1, 72 kHz, 30 V.

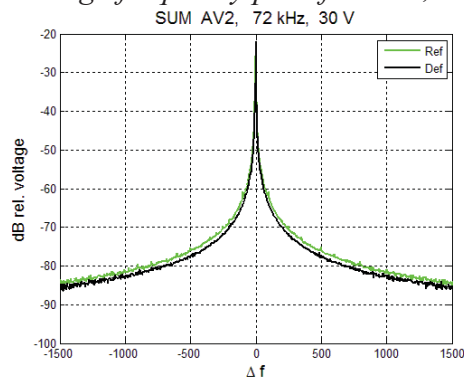


Figure 6.92. High frequency peak for AV2, 72 kHz, 30 V.

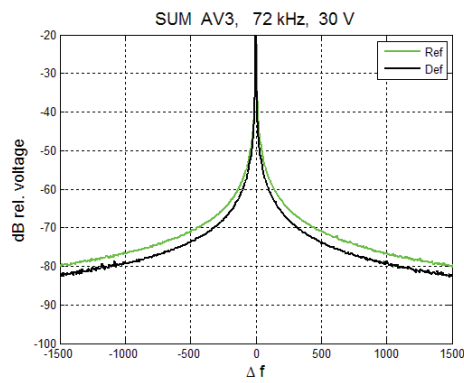


Figure 6.93. High frequency peak for AV3, 72 kHz, 30 V.

6.2.4.1 Area (Increased voltage AV)

The area differences in this case are starting for AV1 at -10 %, for AV2 it is -3 % and at last for AV3 14 %. The difference goes from being clearly negative and is transformed into a clearly positive difference. See figure 6.94 and 6.95.

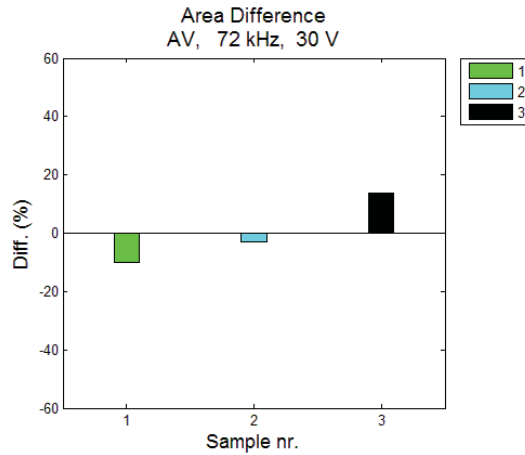


Figure 6.94. Area difference for AV, 72 kHz, 30 V.

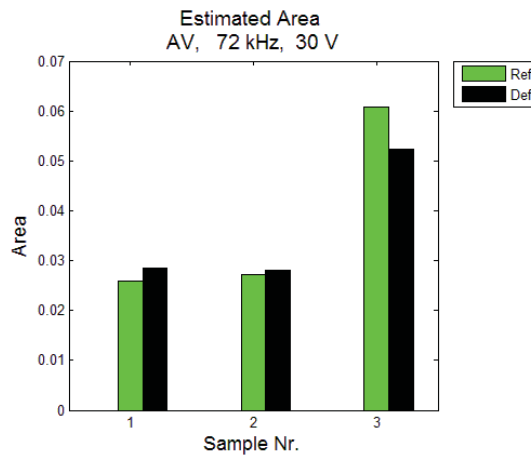


Figure 6.95. Estimated area for AV, 72 kHz, 30 V.

6.2.4.2 Damping (Increased voltage AV)

The damping ratios in figure 6.96 are pretty much equal to the ones for 10 V in figure 6.58. The reference holds a little higher ratio for all three samples, which is what can be seen by looking at the summation plots in figure 6.91-93 since the green reference seem to be slightly wider than the black defect curve. The difference for AV1-3 is 15.4, 10.4 and 12.4%. The results are very much alike the ones for driving voltage 10 V just like for the unmixed defect.

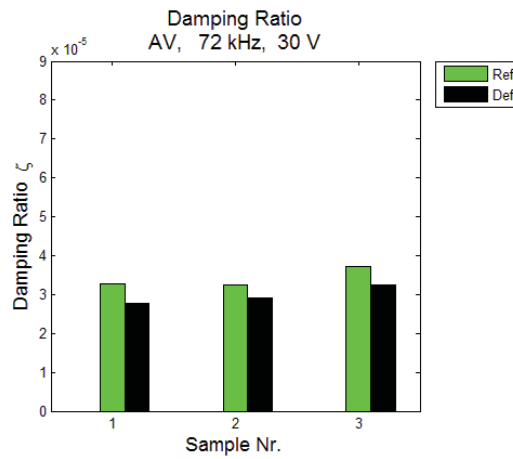


Figure 6.96. Damping ration estimated for AV, 72 kHz, 30 V.

6.2.4.3 Peak Amplitude (Increased voltage AV)

The pattern is the same here as for 10 V, the amplitudes has simply grown a little bigger, naturally since the voltage is increased. The defect part is still higher than the reference in all three samples. See figure 6.97.

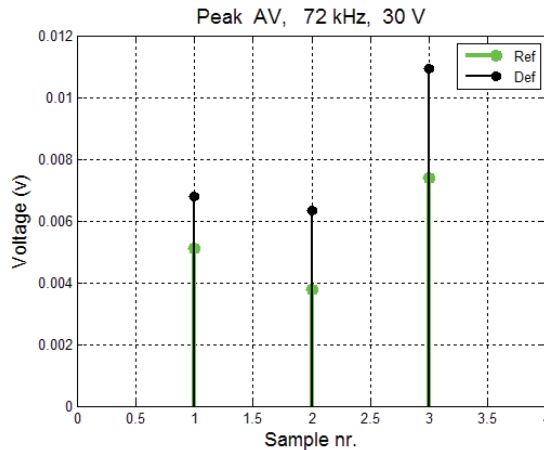


Figure 6.97. High frequency peak amplitude AV, 72 kHz, 30 V.

The following table 6.10 shows an approximation of the amplitudes transitions in dB from main frequency 10 V to the increased voltage. Both the noise floor amplitude and the peak amplitude are compared. However the amplitudes increase can be an obvious outcome of increasing the voltage.

Table 6.10. Amplitudes transitions by increasing the main voltage

Sample	Starting point amp. app in both plots	The main frequency amp. app in both plots
1	$amp \approx -90 \rightarrow -80 < amp < -90$	$amp < -30 \rightarrow amp \cong -25$
2	$amp = -90 \rightarrow amp \approx -85$	$amp < -30 \rightarrow amp < -20$
3	$amp > -90 \rightarrow amp \approx -80$	$amp < -30 \rightarrow amp < -20$

6.2.4.4 Harmonics (Increased voltage AV)

Once again it is at a driving voltage of 30 V for frequency 72 kHz that some more harmonics finally show up. Not only the simple multiples of the input frequency that are picked out and shown in figure 6.102-104, but also some other combination probably between the input frequency and some low frequency not excited on purpose. Nevertheless it is clear that something has happened because of the increased voltage. The behaviors of the harmonics in the three samples are different from each other. In figure 6.102-104 the highest amplitudes belongs to the reference and the defect part in different turns, see also figure 6.101. The pattern of the harmonics is very much alike for the reference and defect part in AV 1 and 2, in AV 3 there are some small differences. For example harmonic nr 5 in figure 6.104 is breaking the pattern similarities for reference and defect part.

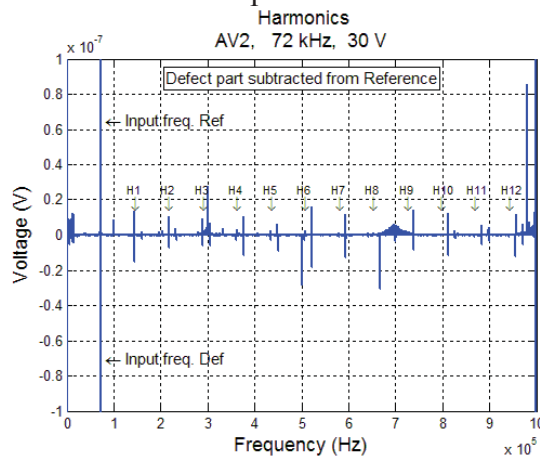


Figure 6.101. Harmonics from defect part subtracted from reference part AV1.

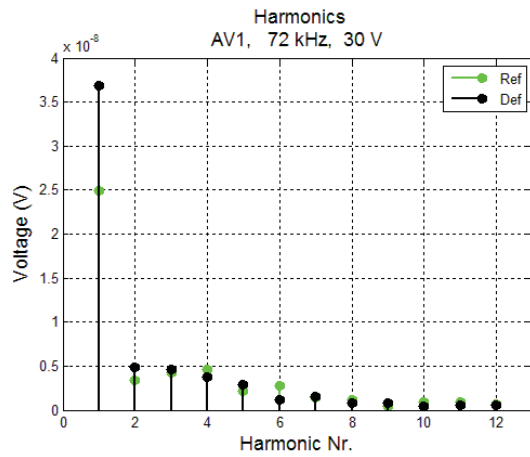


Figure 6.102. Harmonics picked out for AV1.

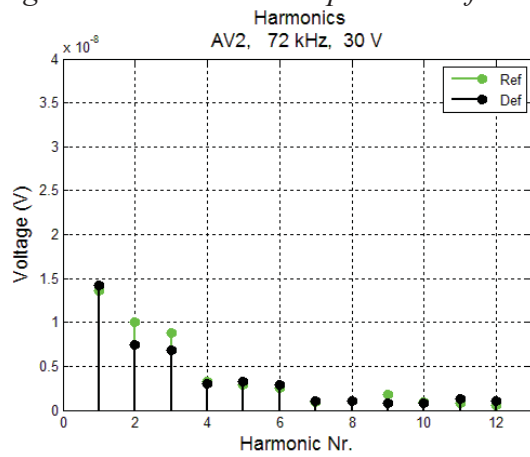


Figure 6.103. Harmonics picked out for AV2.

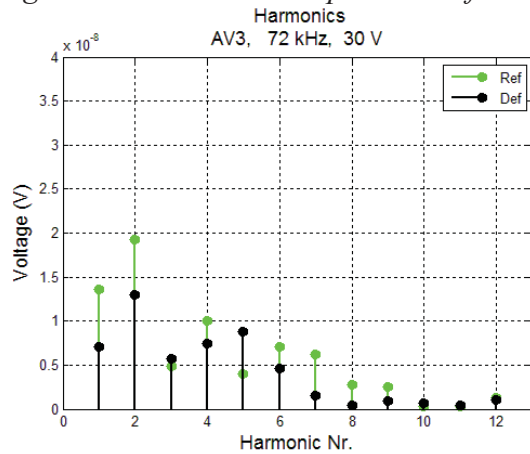


Figure 6.104. Harmonics picked out for AV3.

6.2.1 Conclusion Airvoids

The results from the Air voids are briefly summarized in four tables 6.11-14 below. The following tables show how the different levels of damages are affecting different criteria in each experiment.

Table 6.11. Table indicating if the property in question has increased or decreased after defect introduction. For AV, 72 kHz, 10 V.

Defect material properties in relation to Reference material properties			
72 kHz, 10 V	AV 1	AV 2	AV 3
Area	+	-	-
Damping ratio	-	-	-
Peak Amplitude	+	+	+
Harmonics Amplitude	+	+	-
Harmonics Nr.	=	=	=

Table 6.12. Table indicating if the property in question has increased or decreased after defect introduction. For AV, 34 kHz, 10 V.

Defect material properties in relation to Reference material properties			
34 kHz, 10 V	AV 1	AV 2	AV 3
Area	≈	≈	+
Damping ratio	-	≈	≈
Peak Amplitude	+	-	+
Harmonics Amplitude	-	=	=
Harmonics Nr.	-	-	=

Table 6.13. Table indicating if the property in question has increased or decreased after defect introduction. For AV, 124 kHz, 10 V.

Defect material properties in relation to Reference material properties			
124 kHz, 10 V	AV 1	AV 2	AV 3
Area	-	-	≈
Damping ratio	≈	-	-
Peak Amplitude	-	+	=
Harmonics Amplitude	=	=	=
Harmonics Nr.	=	=	=

Table 6.14. Table indicating if the property in question has increased or decreased after defect introduction. For AV, 72 kHz, 30 V.

Defect material properties in relation to Reference material properties			
72 kHz, 30 V	AV1	AV 2	AV 3
Area	+	+	-
Damping ratio	-	-	-
Peak Amplitude	+	+	+
Harmonics Amplitude	+	-	-
Harmonics Nr.	=	=	-

The results for Air voids are less consistent than for Unmixed granulate. The properties increase and decrease in different ways for many samples and for some the properties are actually equal for reference and defect part. As mentioned before the reference's results are also differing a lot between the three samples. Sometimes the impression is that the results for the defect samples are even more equal than the reference ones. Increasing or decreasing the input frequency also causes differences in the results. Increasing the voltage is though, as for Unmixed granulate, not causing any major differences except the fact that harmonics are appearing.

7 Discussion

In the thesis, we experimentally investigated the materials produced by Tarkett by using the NAW method which is an NDT method. The goals of this experiment were to study different kinds and different levels of damages of the materials. Two different types of defects were introduced to the materials: Unmixed Granulate and Air Voids. Each of them was studied at three different levels of damages.

7.1 Results

The results are not unanimous or obvious but there are some interesting observations made. For Unmixed Granulate the trend is that the studied properties increase from reference to defect material. The increase can be the sign of more nonlinearity caused by the imitated defects. For example a comparison shows that the area under the peak has in all cases increased compared with the reference for the two samples with highest amount of defects. The harmonics are also going towards higher amplitudes which are signs of increased defects causing nonlinearity.

For Air Voids the pattern of the results is more capricious. The properties seem to increase and decrease in different turns and in many cases the results are pretty similar for the reference and defect materials. This might simply imply that the imitated defect of Air Voids in fact contains a smaller amount of defects than the material itself. There were maybe not enough bubbles in the glue, which was the idea of the constructed defect, but instead a medium more homogenous than the reference material. Basically the imitation of defects was maybe not very successful.

7.2 Errors

Since the results are a differing a bit it is interesting to discuss the possible errors in the experiments and analyses. One disturbance found when studying the data from the experiments is the 50 Hz frequency of the electrical system. This frequency was sometimes even more powerful than the input high frequency and therefore its presence was a little blatant. Without having anything to do with the experiment it can show up in the data. It could possibly have been avoided by filtering the signals. Another error was the low

frequencies excited by the impact hammer. Sometimes there were hardly any low frequencies successfully excited and sometimes they were blurred. This can be explained by the material itself or that the hammer hit was not successful. A way to ensure low frequencies presence could be to use a signal generator instead of a hammer and only excite one chosen low frequency. In that way the low frequencies are more controlled and it might result in more useful data.

At last the imitated defects are possible errors. More tests could be carried out with the same or “improved” imitated defects but the results would be considerably more trustworthy if real defect material could be tested. This is something that will be crucial to the development of a model to use directly in the production line since straightforward numbers are essential for that kind of application. The results of the thesis give more of an indication of the possibility to get valuable results than numbers that can be applied right away.

7.3 Using NAW[®] in production

All the properties studied in this work can relatively easy be calculated automatically if the right measurement equipment were available. The equipment could be a dynamic solution where the transducers are attached to the material only by placing them against the material for the time it takes to get the necessary data, preferably automatically. The situation where the measurements should be made is right after the processed material comes out of an extruder. The material will therefore probably be moving constantly and consequently so will the transducers have to do. This would involve some kind of automatic arm and is therefore maybe a little too complex. Another possibility is to investigate if some kind of continuous measuring can be used, with the measurement equipment fastened at one point as the material is passing.

The discussion of the possibility to use NAW[®] in the production at the factory in Ronneby must involve both the good results and the errors that have been coming across this work. Despite the sometimes vague results the method is still considered as a possible tool for Tarkett. Although due to the errors described above more experiments are needed before an implementation in the production can be made.

The possibilities for development are nearly endless for this specific case just as for nondestructive testing in general. So much information can be found simply by analyzing the output of the system without really knowing why some phenomenon occurs. Imagine what could be achieved with ever so slightly better understanding.

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Institutionen för Maskinteknik
Blekinge Tekniska Högskola, Campus Gräsvik
371 79 Karlskrona

Telefon: +46 455-38 50 00