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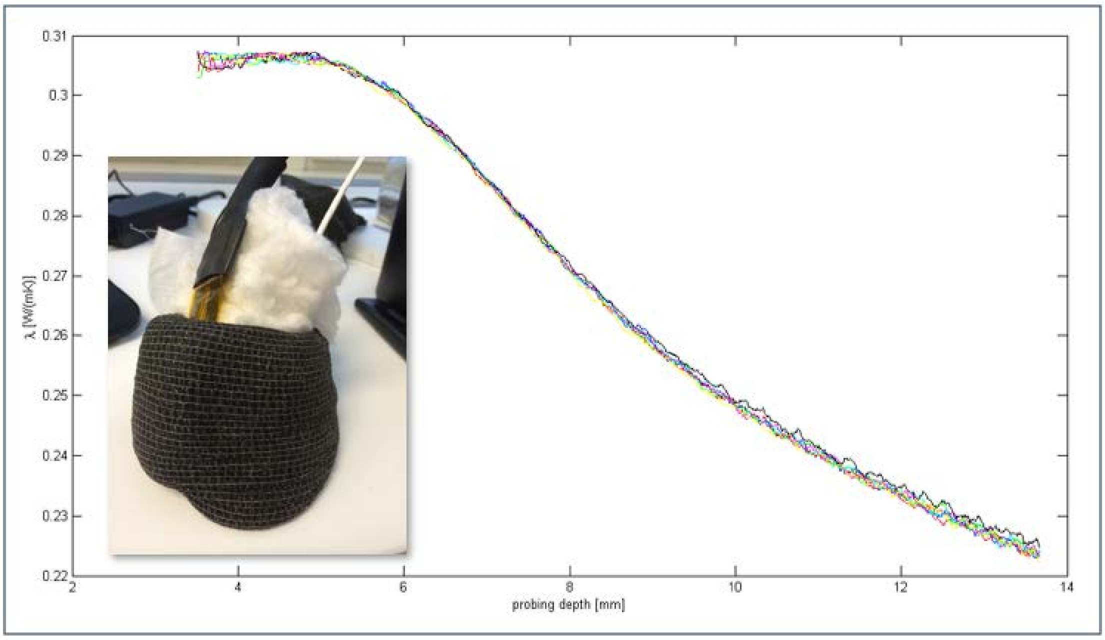

Detecting anomalies in horse hooves using Hot disk measurement equipment

Master's thesis in Engineering physics

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DEPARTMENT OF PHYSICS

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Cover: Measurement of hoof and measurement graph, by Charlotte Lundqvist

Abstract

The aim of this thesis was to investigate the possibility to detect abnormalities in horse hooves using equipment from Hot disk. Measurements were made on dead hooves from real horses using the structure probe feature on the Hot disk TPS 2500S instrument. The hooves were both with and without damages which were created in the lab to mimic real life injuries. After seeing clear differences between the damaged and the undamaged hooves the conclusion is reached that it is probably possible to detect abnormalities in live horse hooves as well using this method.

The measurements and most of the work on this master thesis were completed in 2014 and 2015. The completed version was released in 2020.

Acknowledgements

I would like to thank everyone at Hot disk who provided guidance and support and equipment to make this thesis possible. I would also like to thank Magnus Karlsteen and Maria Sundin, without whom there would be no possibility of combining studies in physics and horses at Chalmers. The work you are doing to make this possible is highly appreciated by many. Lastly I would like to thank family and friends for support and encouragement.

Contents

1

Introduction

1.1 Background

1.1.1 Horses

Horses have been domesticated since around 3600 B.C . The horses were a lot smaller when in the wild measuring about 130 – 140 cm at the withers. The modern horse has got its size from consious breeding by humans. [1] Today the horse has changed from being a mode of transportation and help on the farm to a companion and athlete. Horse sports are becoming increasingly popular which has lead to a steady increase of the number of horses.

The number of horses in Sweden today are estimated to be 362700 which equals about 39 horses for every 1000 citizens. This is quite a high number and puts Sweden in second place in Europe after Iceland when counting horses per 1000 people. [2]

Since the horses of today are very valuable to their owners large sums and lots of time is spent on curing horses from illness and injuries. Some of these problems occur in the hoof of the horse. These injuries are often hard to diagnose.

Horse hooves

Cracks and abcesses in horses hooves are problems that affect many horses. They often lead to severe pain and lameness of the horse and can be very hard to treat for a veterinarian or farrier. The problem with treating them is often that it is hard to locate them and estimate their size. Non necessary cutting in the hoof can then occur due to not knowing how far in an infected abcess lies. This can lengthen the time of recovery and cause more pain for the horse. The method now used to locate these abnormalities are x–rays. When analyzing the x–rays taken of a hoof there is an element of luck involved to spot the cracks or acesses. The x–rays have to be taken at exactly the right angle for anything to show up which makes it very hard to know if there is an abnormality in the hoof or if it was simply missed. The other now excisting method is MRI but this is very expensive to perform on a horse, an expense that is not covered by insurance. Ultrasound bounces against materials such as bone and nails so this diagnostic method is not usable for hooves. So the need for a method to accuratly diagnose hoof illnesses is much sought after by farriers, veterinarians and horse owners.

Another illness that can occur in the hoof is keratoma which is tumors consisting of hoof–like material. These tumors starts growing from the lamellar layer in towards the hoof bone. Often these are only diagnosed when they have grown enough to deform the hoof bone which is very painful for the horse. The deformation in the hoof than shows up on x–rays. At this stage it is also hard for the horse to make a full recovery and in many cases putting the horse down is the only option. For these reasons a new method for diagnosing keratomas would be very useful.

1.1.2 Chalmers Research area

The Area of Advance Material Science at Chalmers has for the past few years extended into the field of sports science, including equine science. There is a lot of research done in equine science from a biological and veterinarian point of view but not much technical research. The research area at Chalmers has grown rapidly over the last two years and now have several different projects running as well as bachelor and master thesis projects.

1.1.3 Hot disk

The company Hot Disk has developed instruments which uses thermal pulses to check for defects in materials such as steel, plastics or even powders. They have together with Chalmers equine science group come up with the idea to measure hoof abnormalities with the help of the technique developed for other materials.

General theory

The thermal conductivity of a material dependends on many things like structure, density, porosity and electrical conductivity. The transient plane source (TPS) technique is able to cover a lot of these transport properties and also a large number of materials as samples. The resistive element is used as both a heat source and a sensor. The TPS can be arraged in different shapes but the sensor used in this project is a hot disk which is a bifilar spiral made of nickel foil and covered with kapton. Finding the thermal conductivity is done by recording the voltage change over the TPS element while its temperature is slightly increased by an electric pulse. The current pulse is of such a length that the sensor can be considerd to be in contact with a infinite solid during the measurement. The length of the measurement has to be chosen so that the boundaries of the sample will not affect the temperature increase of the sensor. [3] During a measurement a current passes through the nickel which generates heat at the surface of the material. The heat travels through the material at a rate dependent on the properties of the material. The sensor temperature response versus time is recorded and from this the material characteristiscs can be recorded.[4]

Sensor

The sensor is built up of a flat continuous double spiral made of nickel and covered by a layer of kapton, which is a polyimide film, on both sides. The layer of kapton acts both as electrical insulation from the sample and mechanical support for the sensor. The sensor used in this project is called 8563 and has a radius of 9.9mm. [4]

During a measurement a current passes through the nickel which generates heat at the surface of the material. The heat travels through the material at a rate dependent on the properties of the material. The sensor temperature response versus time is recorded and from this the material characteristiscs can be recorded. [4]

Structure probe

In this project the feature structure probe on the Hot disk instrument TPS 2500S is used. This setting gives a value of the thermal conductivity, λ, as a function of the probing depth. [4] Sub–surface structural variations can therefore be monitored in a non–invasive way. [5]

The structure probe method is used for measuring the thermal properties of inhomogeneous or layered materials. The structure probe method can measure the variations of the thermal properties in the direction perpendicular to the surface which is being heated by the sensor. The sensor both heats the surface and measures the temperature at the surface. These temperature values are each associated with a time point. To estimate the thermal properties of the material with physical and mathematical models, at least two sets of measurements has to be made. Each associating a temperature value with a time point as in the first set but in the second set at least one temperature must be taken at a different time point than any in the first set. These sets are than treated mathematically to find the thermal properties, this is discussed below.

To get the thermal properties as a function of distance from the surface it must first be assumed that the heat flow that the surface is subject to is one dimensional. This assumption can be made during a relatively short period of time when the heating of the surface starts. How short of a time this can be assumed depends on the material. For a material with high conductivity the time when the assumption is correct is shorter and for a material with low conductivity this time is longer. The maximum time to make an accurate measurement also depends on the area to which the heat is applied. For a larger area the heat flow can be assumed to be one dimensional for a longer time than for a smaller area. It would be possible to reduce the influence of boundary effects by applying heat to quite a large area and making the temperature measurements in the center of the heated area.

In general when using the structure probe method the assumption of a one dimensional heat flow can be made for a depth or distance from the surface that approximately the same as the radius of the circular area being heated. The ideal size of the sensor is below $10cm^2$ and preferably less than $5cm^2$. A larger probe will give better accuracy but a smaller one will make it easier to distinct points and a smaller one is also easier to handle. For most applications the active area is less than $1cm^2$ and for some applications, such as microelectronics and the human body, the active area can be as small as a few square millimeters. The thermal properties, thermal conductivity and diffusivity, can be estimated from the measured temperatures. In order to make the estimation the measurement has to be made during such a short time that the heat flow can be assumed to be linear in a direction perpendicular to the heated surface. Than the following equation can be used:

$$\Delta T(t_i) = A_z + P_o \cdot (\pi^{\frac{3}{2}} \cdot r \cdot \lambda_z)^{-1} \cdot f(\tau_{zi}) \tag{1.1}$$

$$t_i = t_z, \ldots.., t_z + t_{subset}$$

Where $\Delta T(t_i)$ is the temperature increase at time t_i, A_z is a free variable; representing a thermal contact resistance between sensor and the surface of the measured object; P_o

is the heating power applied to the sensor, r is the radius of the sensor, $_z$ is a free variable representing a best-fit thermal conductivity associated with d_z or t_z; τ_{zi} is a dimensionless time; $\tau_{zi} = (t_i - t_{z,corr})^{0.5} \cdot \phi_z^{-0.5}$; $t_{z,corr}$ is a free variable representing a time correction; ϕ_z is a free variable representing a characteristic time, $\phi_z = r^2/a_z$ for a disk shaped sensor; a_z is the best-fit thermal diffusivity associated with d_z or t_z; $\phi_{average}$ is a characteristic time, $\phi_{average} = r^2/a_{average}$; and $f(\tau)$ is a dimensionless time-function, depending on the particular geometry of the sensor and evolution of heat flow.

For short times, corresponding to essentially one dimensional heat flow, $f(\tau) = \tau$ for any plane sensor geometry (disc-shaped, square, strip-shaped etc.) Guidance for selecting parameters and functions to be used, e.g. for $\tau_{z,corr}$ or $f(\tau)$, may for example be found in ISO 22007-2. [6]

In the equation above the thermal properties are related to time points. To relate them to depth instead the following equation can be used:

$$d_z = const \cdot (a_{average} \cdot t_z)^{0.5} \tag{1.2}$$

Where d_z is the probing depth; const is a dimensionless constant in the interval [1,3]; $a_{average}$ is the average thermal diffusivity inside the measured object; t_z is the time representing the time interval selection of time measurement points $[t_z, t_z + t_{subset}]$. This makes quite a good approximation for the depth but it could be improved by choosing the constant to some reference for material or group of material having similar thermal transport properties. [6]

These two equations together give the thermal conductivity, λ, as a function of the depth from the surface which in turn gives information of how the structure varies.

1.2 Aim

The aim with this project is to verify that the measurement method using thermal pulses can be used on horse hooves and to connect the results with known illnesses of the horses hoof.

1.3 Delimitations

The project will not include developing a product ready for market. Or any attempt to explore the market for such a device. Only one day of tests on real horses has been done so that is not thoroughly investigated in this project. The conclusions are drawn from measurements on dead hooves.

1.4 Disposition

In chapter two the methods are described which includes the experimental setup of the measurements. In chapter three the results from the measurements are presented in the form of graphs. Chapter four contains the discussion of the results in chapter three. In chapter five the conclusions are presented.

2

Method

2.1 Measurements in lab

For all the measurements the instrument TPS 2500 S, developed and built by Hot disk, was used. The sensor used was a 8563 sensor which has a diameter of 9.9 mm. The setting called structure probe was selected which means that the instrument is measuring thermal conductivity, $\lambda\ W/mK$, as a function of depth in the hoof. Or more precisely it measures the temperature response in the material and then the software calculates the above relation.

The measurements were one sided which means that only one side of the sensor is in contact with the material being measured. The other side is covered with a highly insulating material to make the heat from the sensor travel into the material that is measured and not into the material at the back of the sensor. In most cases when this instrument is used the sensor is placed between two slabs of the material that is being measured, but since this is not possible for a living hoof the one sided alternative has to be used. This has to be selected in the software before starting the measurement.

The sensor both heats the sample and at the same time measures the way the hoof reacts to the increased temperature. For each measurement the instrument starts with measuring the temperature drift of the sample. This means that it measures the actual temperature of the sample over 40 seconds. This is then shown in a graph. Ideally it should be a horisontal graph with the room temperature as the value on the y – axis, this shows that the sample is in thermal equilibrium with the surrounding air. If the temperature has not been stable during the measurement this can affect the result and measurements with a large temperature drift should for that reason be discarded. To avoid a large drift it is important to let the sample rest and adjust back to room temperature after it being handled or a measurement has been made. Since a dead hoof has quite low thermal conductivity this can take some time. As a rule at least two hours have been left between measurements except at the start of the project when one hour was thought to be enough. After the setup was compleated a test run was made to make sure that the contact between the sensor and the hoof was satisfactory. Then two hours had to pass before the next measurement if the contact was good. These test runs have not been included in the results. At the start of the project it was thought that one hour would be sufficient but after difficulties reproducing the results the proceedure was changed to two hours. After this change the data reproduced nicely.

After the drift measurement the real measurement is taken where the sample is heated a few degrees Kelvin. The sensor heats and measures the thermal response of the sample simultaniously. After the measurement a graph of temperature increase as a function of time appears and a graph of the temperature drift. The thermal conductivity, λ, can then be calculated by the software after giving it the heat capacity C_p as an input. The heat capacity was guessed at the start and after the calculation the slope of the curve would tell if the guess was right. The start of the curve should be horisontal since the material in the hoof, and therefore λ, is the same the first few millimeters. If the C_p is wrongly guessed the curve will have a steeper slope than it should. By changing the heat capacity until the slope is horisontal at the start the right C_p can be found.

All the measurements in lab where made on dead hooves which had been treated for conservation. There where four different hooves all of different sizes and from different horses. Two of them were white and two black which is the two colour a horse can have on its hooves. A picture of the four hooves can be seen in figure 2.1 where the smallest hoof is set up for a measurement. The black hoof at the back of the picture is in reality the biggest of the four.

2.2 Experimental setup

The experimantal setup was designed to mimic a measurement on a real horse. For this reason vetflex, a flexible bandadge which is often used on animals, was used to fix the sensor to the hoof. At the start of the project conductive paste was used between the hoof and the sensor to increase the contact. Since this paste is not very good for the enviroment later measurements were made without it. The contact was not a problem without the paste but the sensor was a lot harder to fix to the hoof since the kapton is smooth which means there is not much friction between the hoof and the sensor.

Figure 2.1: All four dead hooves that were used in the project.

Before the sensor was attached the hoof was polished using sandpaper. This was done to get a smooth surface since this will increase the contact and therefore the quality of the measurement.

The sensor was then placed on the hoof roughly in the middle of the hoof, in respect to height, on the side that was to be measured. Three positions were used: the left side of the hoof, the right side of the hoof and the front of the hoof. On top of the sensor a slab of insulating packing material was placed. The insulation and the sensor was then fastened with vetflex. The vetflex was wound as tightly as possible around the hoof to maximize the contact between the sensor and the hoof and to prevent the sensor from moving. This tightness around the hoof will not pose a problem for a living horse since their hooves are very hard. The empty part of the hoof (where the horse would be attached if it was not dead.) cotton wool was placed to give insulation and prevent rapid air flow inside the hoof. After that the sensor for measuring the reference temperature was attached to the hoof but not near the measuring sensor.

A picture of the experimental setup is shown in figure 2.2.

Figure 2.2: Experimantal setup with the sensor attached to the hoof with vetflex. The hoof is then filled with cotton to get an insulating background and to prevent air flow inside the hoof. The white cable is the reference temperature sensor and the black cable is the sensor taking the measurement.

2.3 Hoof defects

All the hooves in the project were without defect so to be able to find out how a defect would affect the measurements defects had to be created artificially.

2.3.1 Empty cavity

Since hoof material is quite hard when it has dried a knife and a hammer had to be used to create a cavity. The cavity was made on the inside in the lamellar layer. Due to the quite crude method of producing it, the cavity did not turn out very symetrically. The cavity measures about 5–10 mm across.

Figure 2.3: The created cavity on the inside of the hoof.

2.3.2 Cavity with aluminium foil

Hoof abcesses are cavities in the hoof that are usually filled with blood or pus. To mimic this structure in the lab some aluminium foil was pressed into the cavity described above. Aluminium foil was choosen since it conducts heat at a different rate than the hoof itself. This is because the foil has a different (much higher) thermal conductivity compared to the hoof. There should therefore be a change in the graph at the depth where the foil starts. If there would be blood or pus in the cavity instead the graph would still change but in some other way.

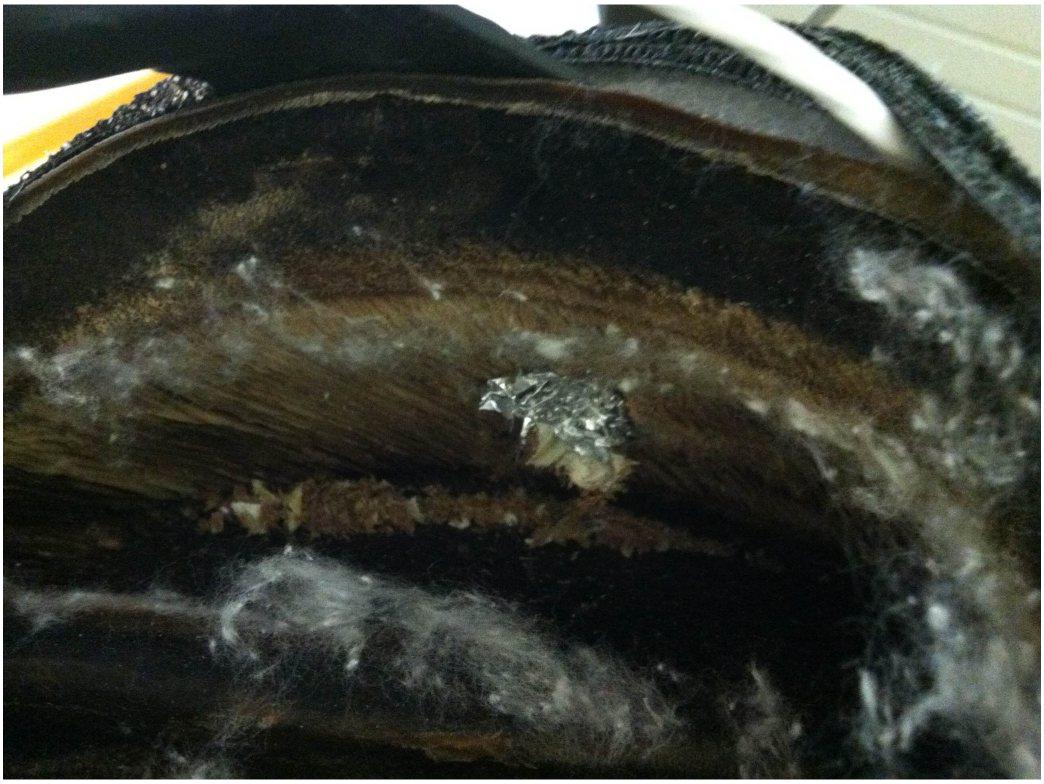

Figure 2.4: The created cavity with a piece of aluminium foil pressed into it.

2.3.3 Blu–tack simulating keratomas

Keratomas are tumors made out of hoof-like material that grows from the hoof and inwards towards the hoof bone. To mimic a keratoma in the lab a sphere of blu–tack was attached to the inside of the hoof.

Figure 2.5: The blu–tack is attached to the inside of the hoof to mimic a keratoma.

2.4 Live horses

Measuring on a live horse is, of course, a lot harder than measuring on dead hooves in a lab. Mostly due to the fact that live horses are very reluctant to stand still. When a horse puts weight on one of its hooves the horse changes the blood flow in the hoof. This will inevitalby change the temperature of the hoof and therefore affect the measurements. To minimize the movement of the horses two of three horses participating in our small study were sedated. The third horse was an uncommonly calm one. Even under sedation the horses were changing the weight between their hooves. To avoid this a hoof stand was used to take most of the weight of the hoof. When one of the hooves is raised the horse prefers to place the weight on the three remaining on the ground, at least when the horse is sedated. When they are not sedated they could easily decide to remove the raised hoof or place weight on it.

3

Results

3.1 Reproducability

One of the goals with this project was to verify that measurements could be made that were reproducible. It is important for a diagnostic method to be able to have a clear standard for what is normal. Otherwise it is impossible to tell what is a damaged hoof and what is simply a variation in the measurements.

In figure 3.1 seven measurements on the smallest hoof in the same spot is shown. The standard deviation was calculated for the seven curves at each measurement point. The standard deviation was calclated for each measurements point and the average deviation is 0.38% of the average measurement value.

In figure 3.2 thirteen measurements on the small white hoof taken in the same spot are shown. There where two hours between each measurement. The standard deviation for these thirteen measurements, calculated as above, is 0.31% of the average measurement value. This is close to the standard deviation for the measurements on the smallest hoof above.

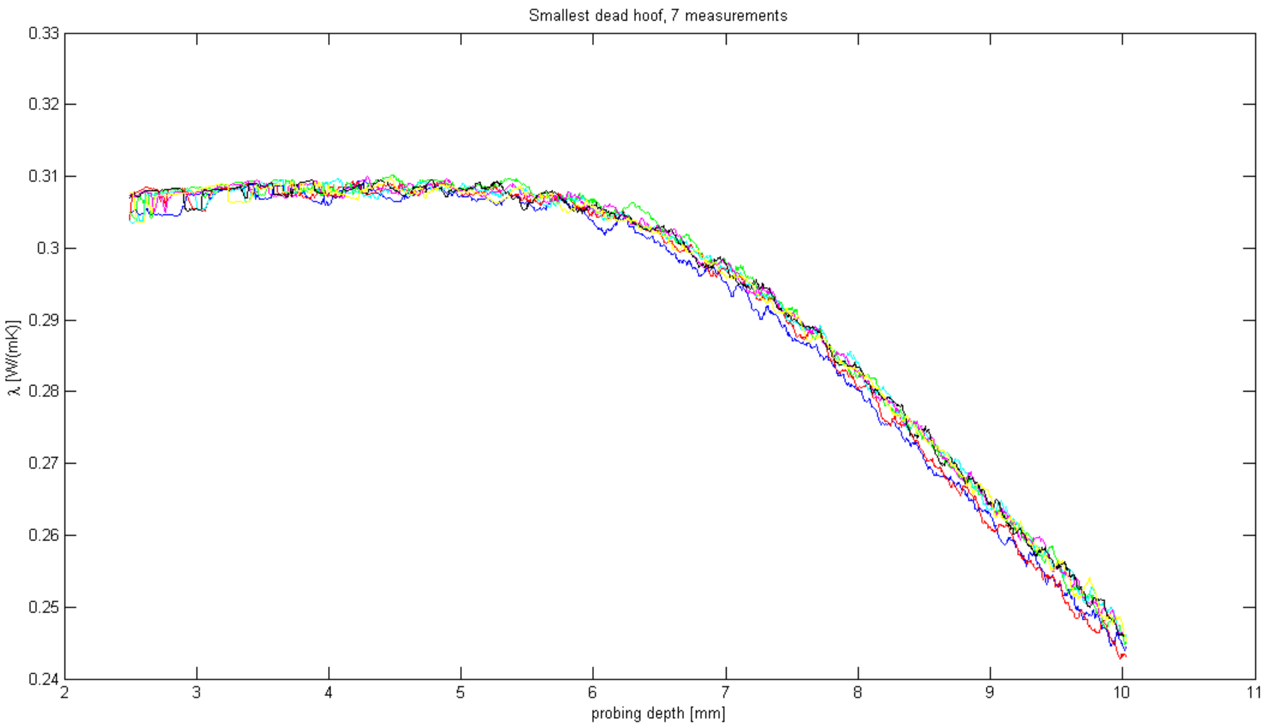

Figure 3.1: Seven measurements on the smallest of the dead hooves taken in the same place with two hours in between.

3.2 Measurements around the hoof

To understand how the measurements on the different part of the hoof looks the smallest dead hoof in the project was measured on three positions around the hoof. On the left side, the right side and in the front of the hoof.

In figure 3.3 the results of these measurements can be seen. All curves are an average of seven measurements. The blue curve is the average of the measurements on the front of the hoof.

The red curve corresponds to the average for the left side and the green to the right side of the hoof. The curve for the front of the hoof is horisontal longer than the curves for the two sides of the hoof. This means that the hoof wall is thicker at the front of the hoof than on the two sides. The standard deviation was also calculated for these measurements.

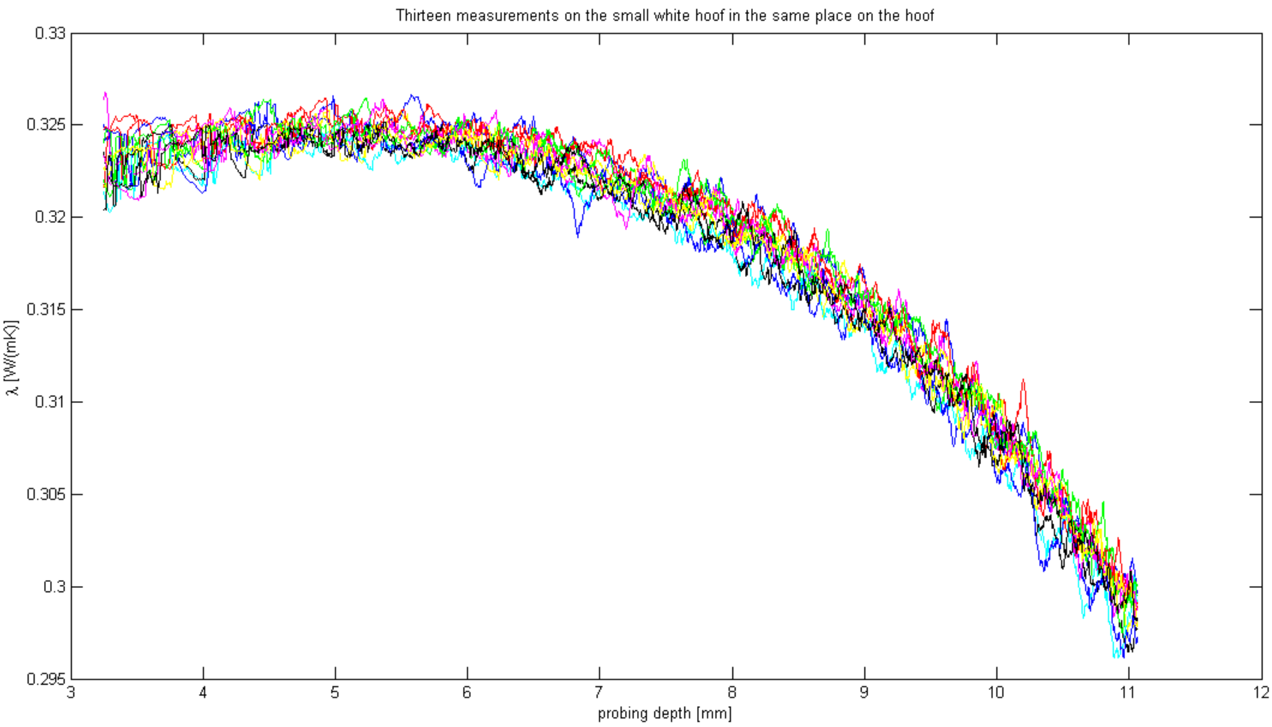

Figure 3.2: Thirteen measurements on the small white hoof taken in the same place with two hours in between.

The measurements of the front of the hoof are the same as the ones plotted in figure 3.1 with the standard deviation of 0.38%. The standard deviation for the measurements on the left side of the hoof is 0.57% and for the right side of the hoof it is 0.36%.

3.3 Hoof with defects

3.3.1 Hoof with cavity

The dead hooves in the project were all without defect. To be able to measure the effects of defects on a hoof they had to be created. This is described in section 2.3. The result of these measurements can be seen in figure 3.6 which shows the average of five measurement for a hoof with and without cavity. Curves has been fitted to these averages and are displayed in figure 3.7.

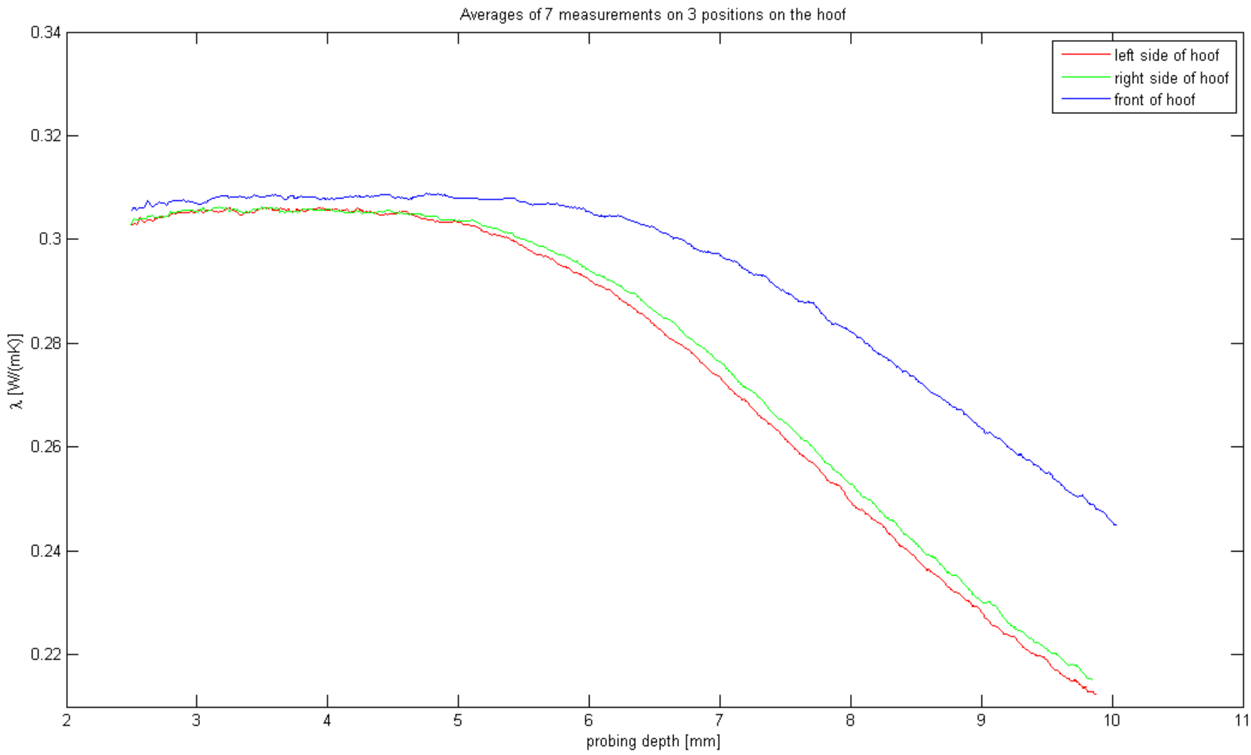

Figure 3.3: Three sides of the smallest hoof. The left and right side are nearly the same. In the front of the hoof the hoof wall is thicker.

3.3.2 Aluminium foil

In the cavity described above aluminium foil was pressed in. Instead of seeing a decline in λ, as for the empty cavity, it increased before declining again. This is what would be expected since aluminium conducts heat very well compared to hoof material.

This was done to simulate a hoof abcess wich is basically a cavity containing something that has different thermal conductivity than the hoof itself. In figure 3.8 five measurements of a hoof with a cavity with aluminium foil inside it is shown.

In figure 3.9 the average of these measurement is plotted together with the averages for the hoof without a cavity and with an empty cavity. Curves were then fitted to these three averages and the result of this can be seen in figure 3.10.

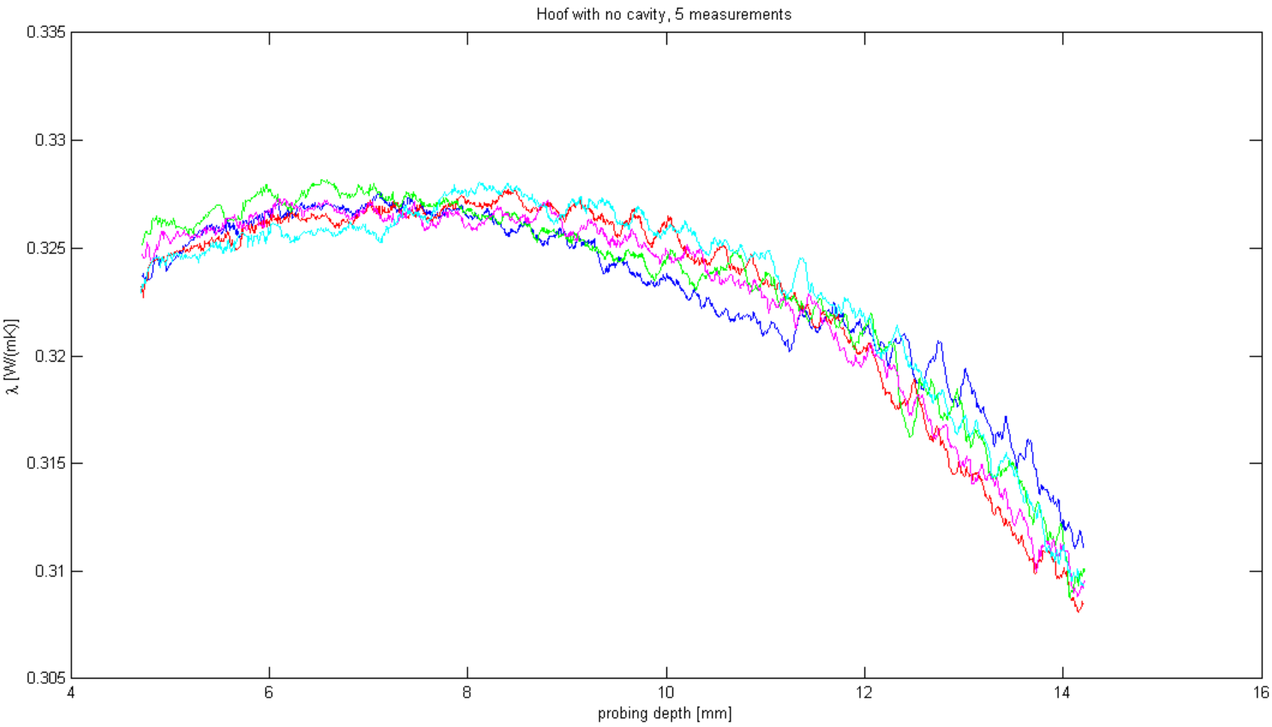

Figure 3.4: Five measurements of the biggest hoof without any damage.

3.3.3 Growth made from blu–tack

To verify that a growth could be detected measurements on the same hoof and in the same place were made with and without a simulated growth. The growth was made out of blu–tack as described in section 2.3.3.

These measurements were made on the smallest hoof used in the project. Figure 3.11 shows seven measurements done on the hoof without the growth and figure 3.12 shows seven measurements with the growth placed on the inside of the hoof.

To make a comparison the averages of the measurements with the growth and without it were plotted in the same graph which is shown in figure 3.13.

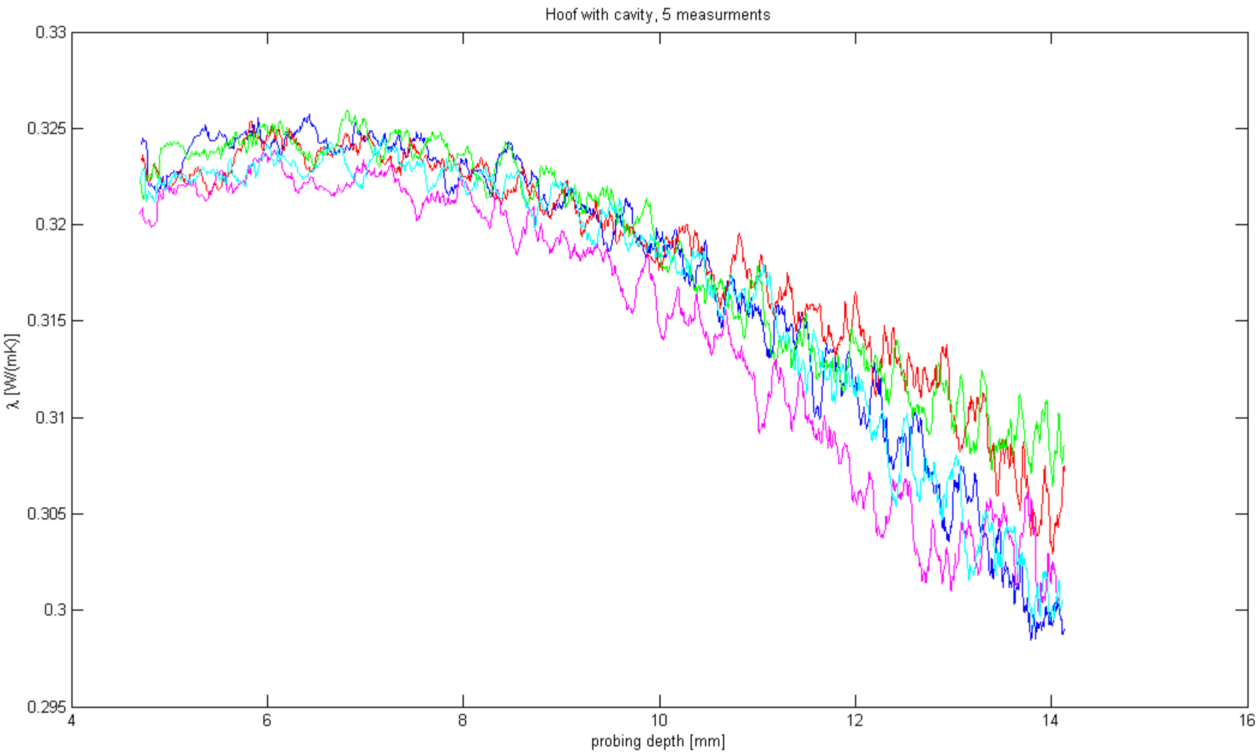

Figure 3.5: Five measurements of a hoof with cavity on the same hoof and in the same place. The measurements have at least one hour between them.

3.4 Live horses

Since only one day was spent measuring on live horses in this project the number of measurements that was without disturbance are limited. Most of the disturbances were created when the horses moved and some from the lack of contact between the sensor and the hoof.

In figure 3.14 two measurements on the same horse and hoof can be seen and the average of the two of them. The two measurements are very similar in the shape of the curve and difference in the height of the curve is only marginal. The pink curve represents the average between the two curves.

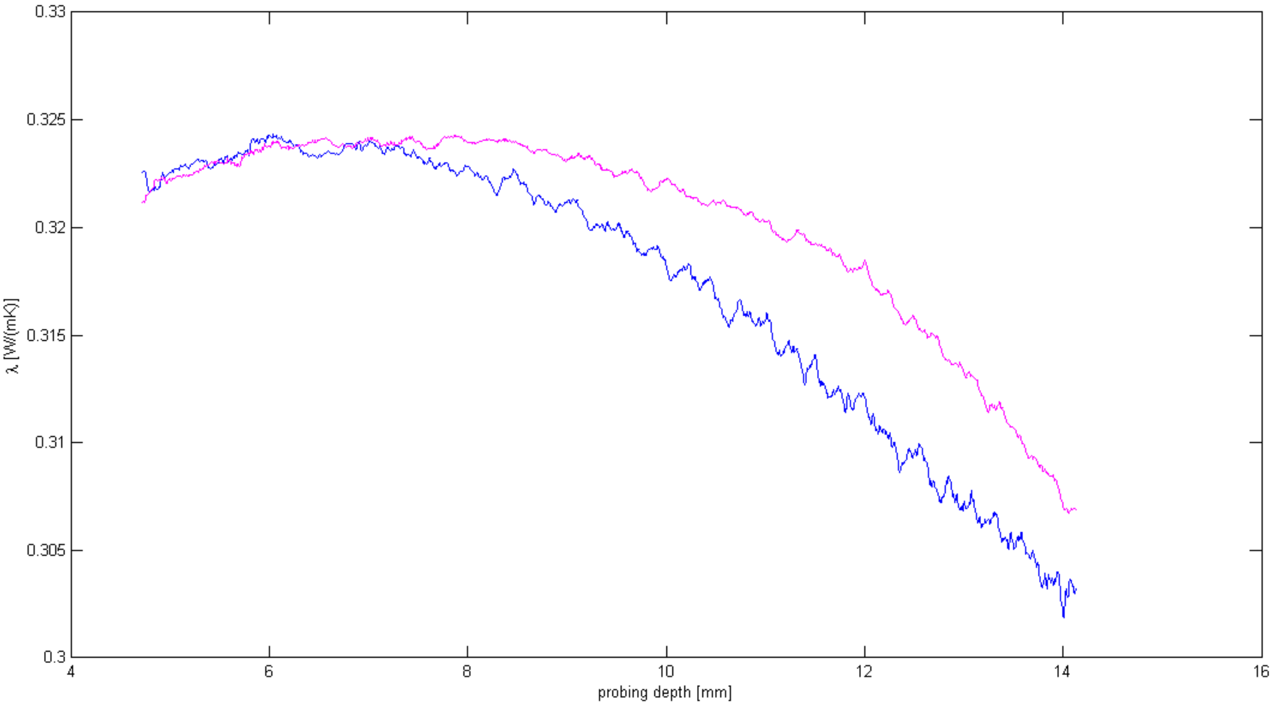

Figure 3.6: Averages of five measurements for the hoof without cavity (pink curve) and the same hoof with a cavity (blue curve). The thermal conductivity λ decreases earlier for the hoof with cavity.

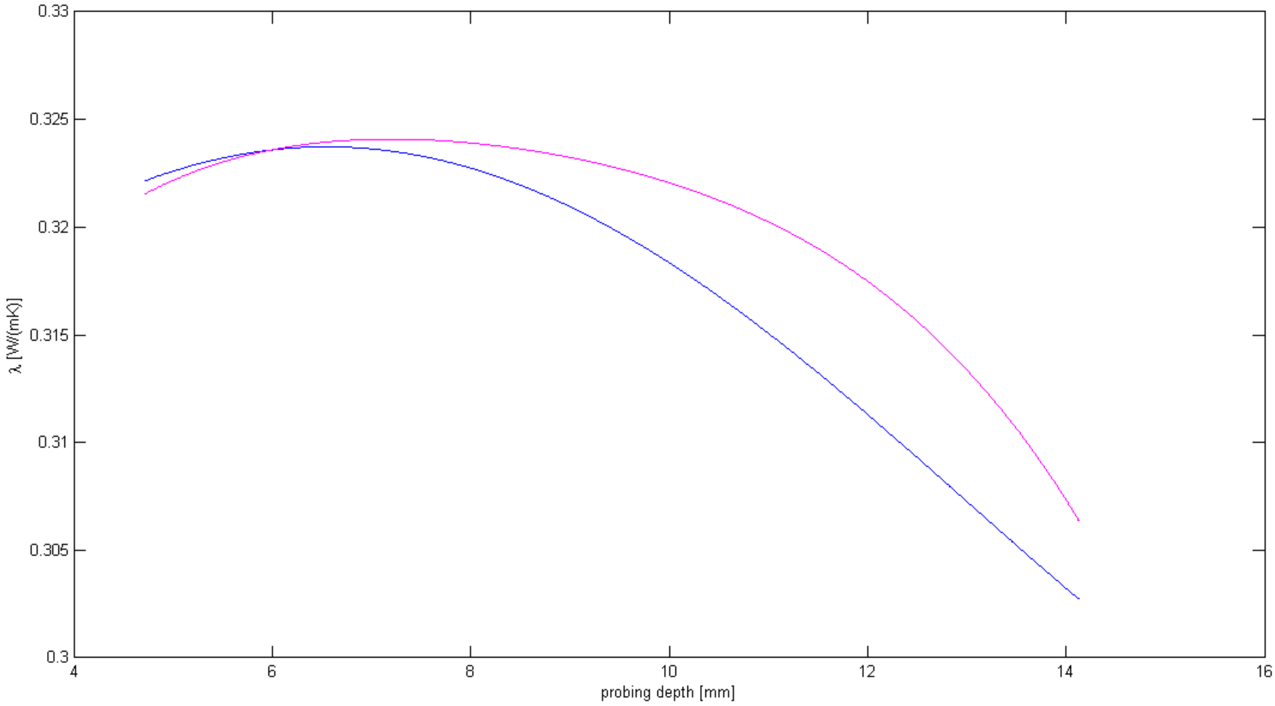

Figure 3.7: The same measurements as in figure 3.6 but here with curves fitted to the averages to show the shape of the curves clearer.

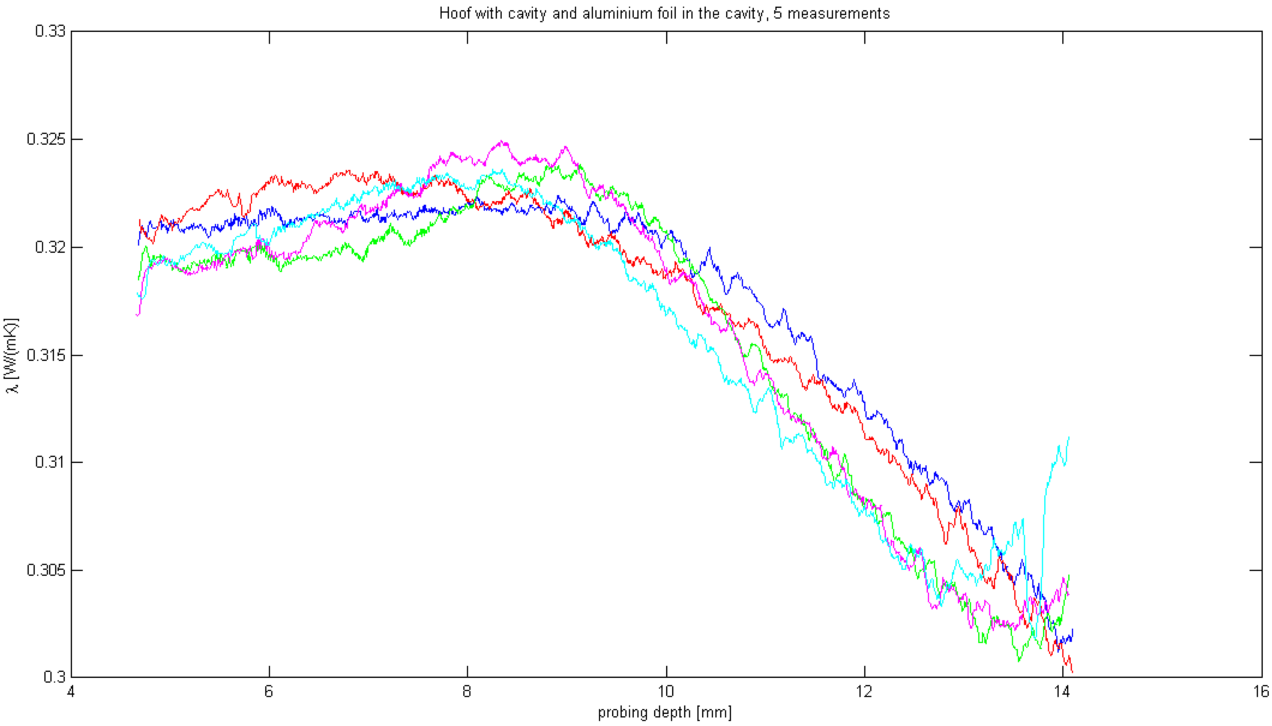

Figure 3.8: Five measurements on the hoof with the cavity and aluminium foil pressed into the cavity. All measurements are done on the same hoof and in the same place on the hoof and with at least one hour between them.

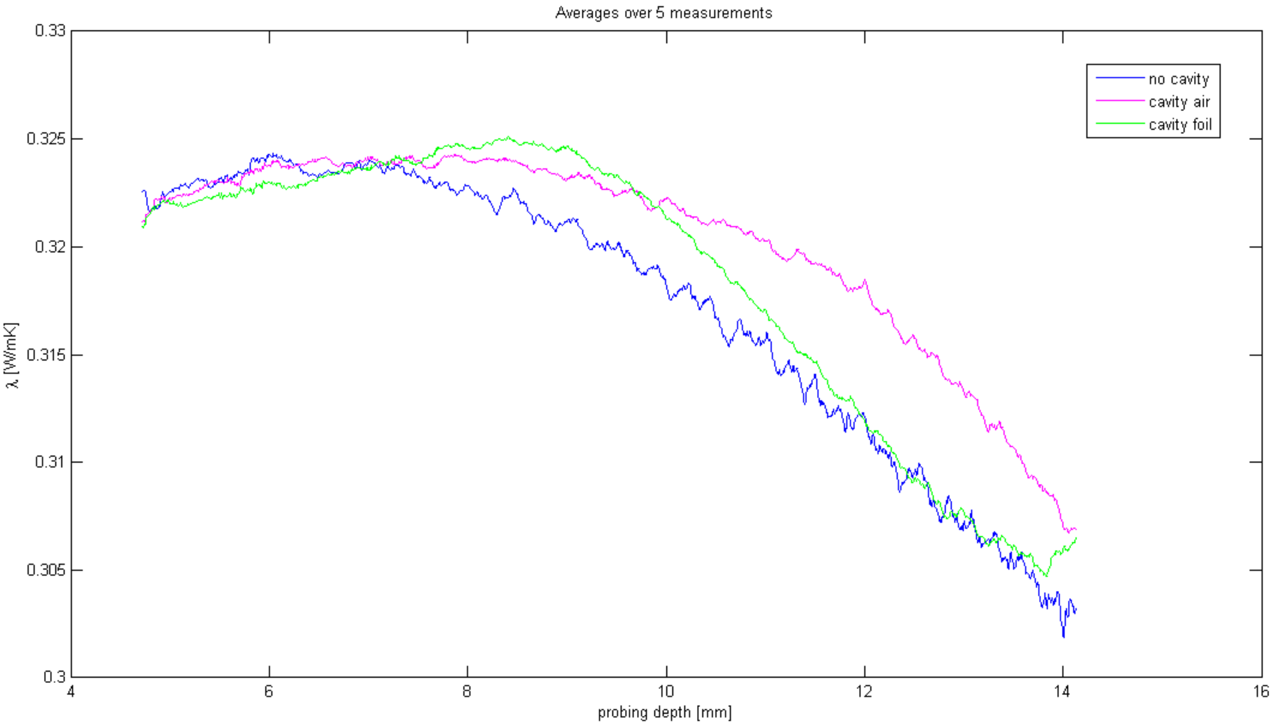

Figure 3.9: Averages of five measurements for hoof with out defect (pink), hoof with cavity (blue) and cavity with aluminium foil (green).

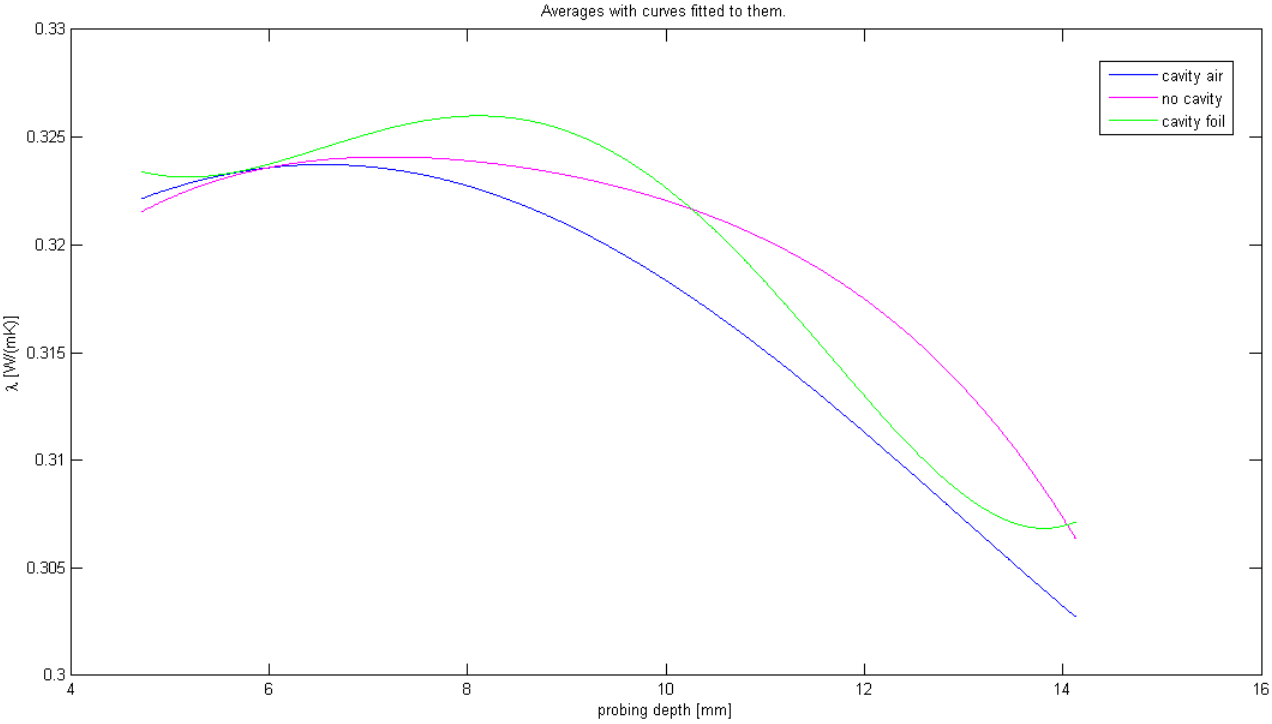

Figure 3.10: Fitted curves to the graphs for a hoof without a defect, with a cavity and with a cavity with aluminium foil in it. The fitted curves are based on the data in figure 3.9.

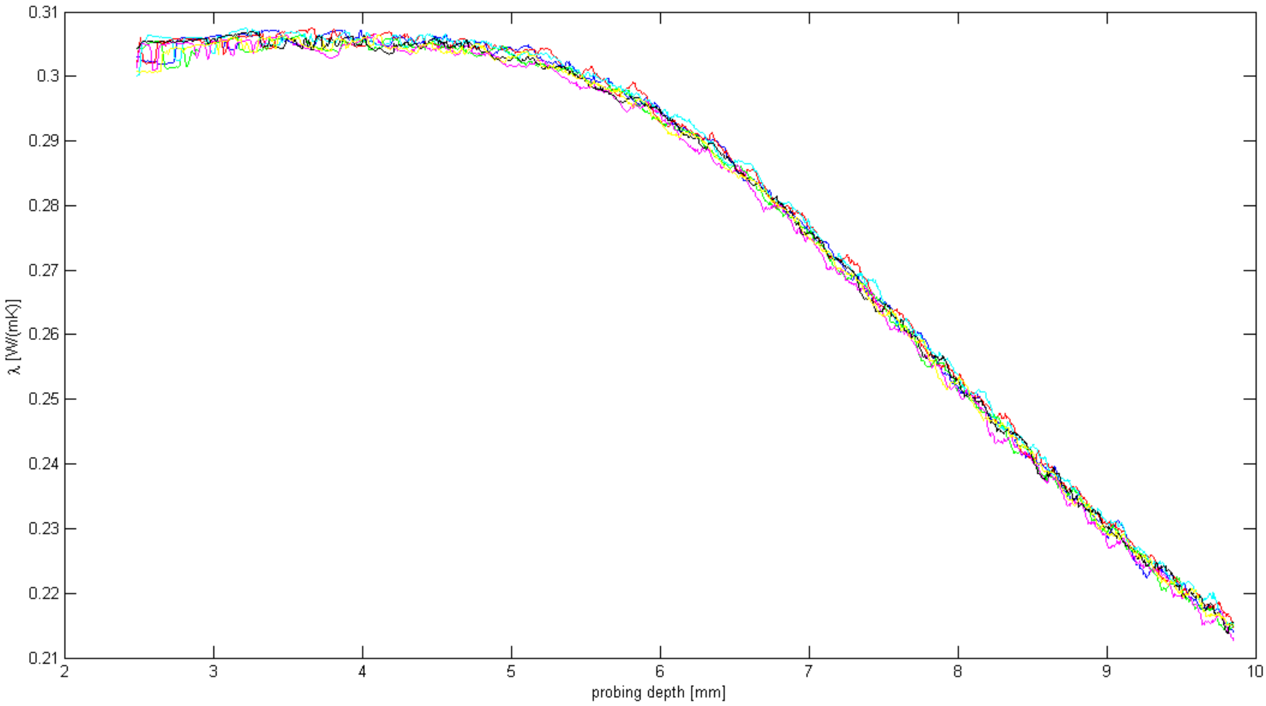

Figure 3.11: Seven measurements on the same hoof and in the same place as the blu–tack later was attached.

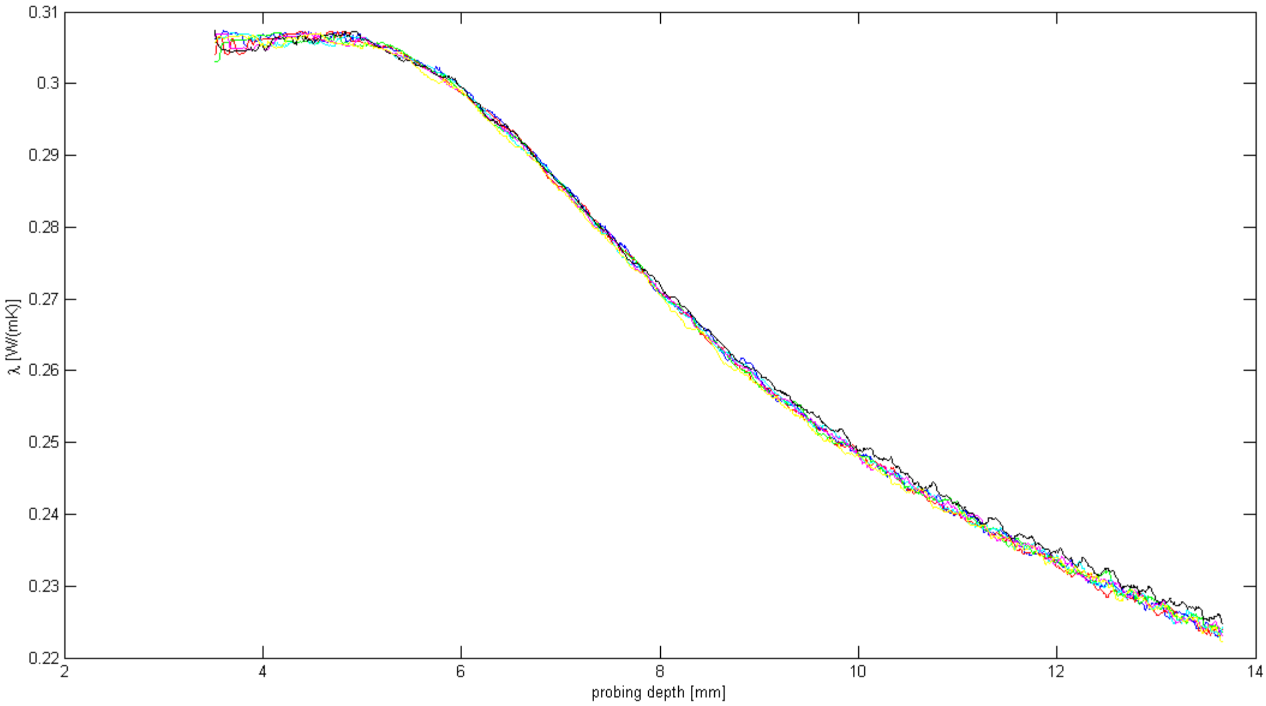

Figure 3.12: Seven measurements on the smallest hoof in the same place as in figure 3.11 but with a simulated growth made out of blu–tack. This was done to mimic a keratoma.

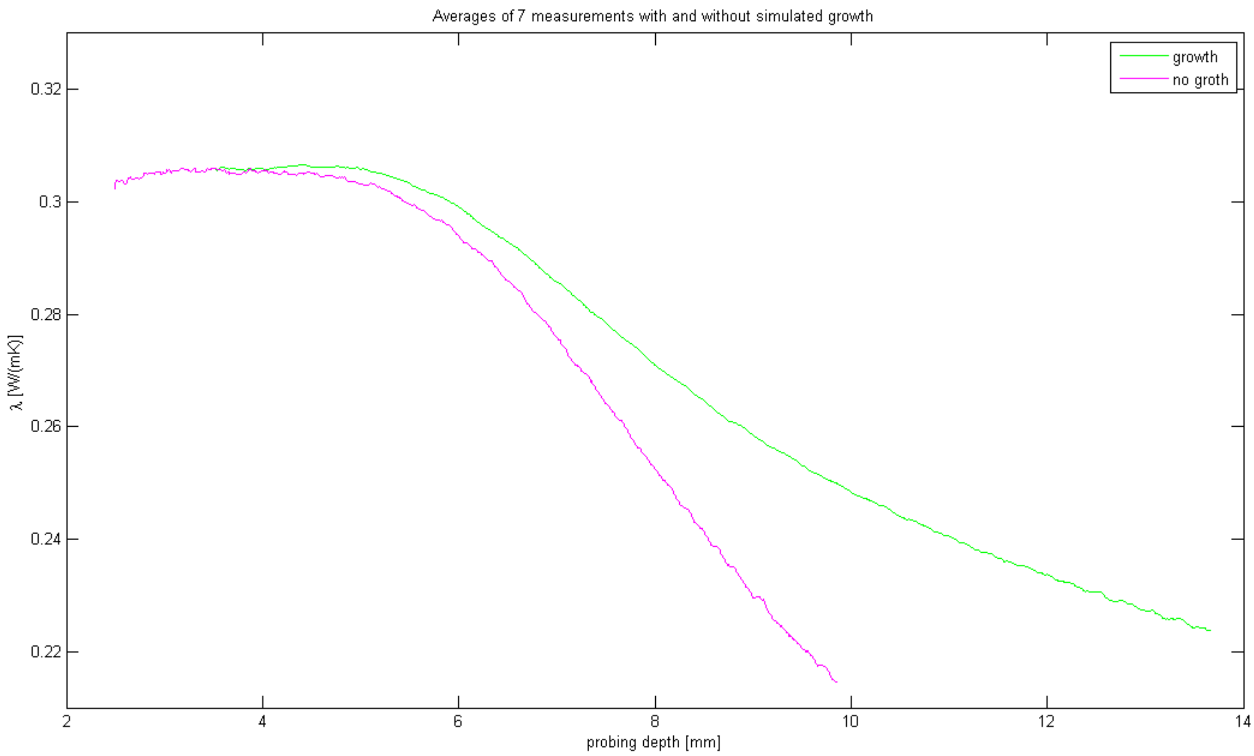

Figure 3.13: Both curves are based on an average of seven measurements. The pink curve is of a hoof without defects and the green curve is of the same hoof in the same place but with a simulated growth of blu–tack.

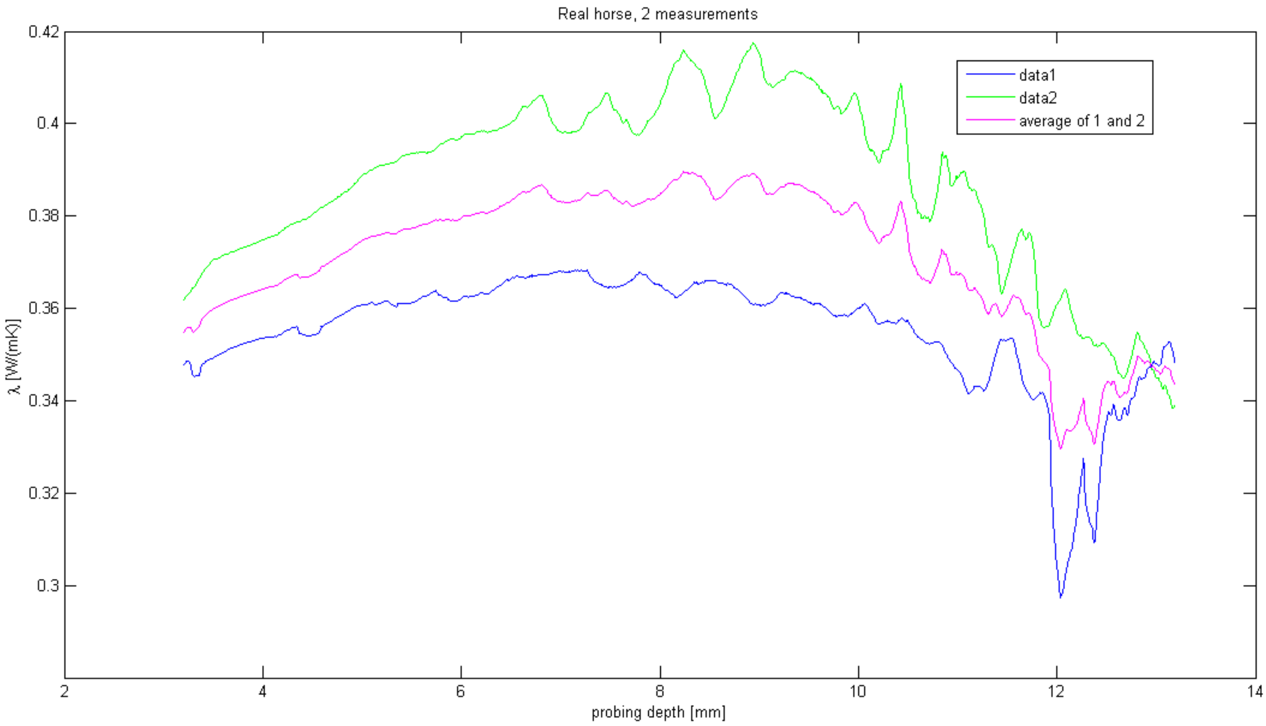

Figure 3.14: Two measurements on the same hoof of a live horse. The pink curve represents the average of the two measurements.

4

Discussion

4.1 Reproducability

A large part of the aim for this project was to verify that measurements were going to be reproducible. This is important for a diagnostic method. The first measurements were made with one hour in between each measurement but this proved to be too short a time for the hoof to cool back to room temperature after the heat was added during the measurement. Even if the temperature at the site of the sensor only increases one to three Kelvin. The result from these measurements were by no means bad the only downside was that they seemed to vary a small bit in thermal conductivity but the curves stayed the same shape. When taking the average of five values this effect is not very significant. This slight variation can be seen in figure 3.4 where measurements of the biggest hoof without any damage are plotted.

To improve the reproducability the time between each measurement was increased to two hours which proved to be successful. This took away the effect of the deviation in thermal conductivity and the shape still stayed the same. An exampel of this can be seen in 3.1 where seven measurements are plotted in the same graph. Just by looking at the graph it is clear that they deviate very little from each other and the standard deviation was found to be 0.38% of the average measurement value, which is a very small deviation.

To verify that the same accurate result could be achived for a different hoof, thirteen measurements were made on the second smallest hoof which can be seen in figure 3.2.

These were all made in the same spot on the hoof and with two hours in between each measurement. Just by looking at the graph it is clear that these are very consistent measurements and the standard deviation was found to be 0.31% of the average values at each point.

The standard deviation for both of these hooves is small which proves that the measurement method can be relied on to produce the same result for identical measurements, at least for dead hooves.

4.2 Damaged hooves

When it was established that reproducible measurements on an undamaged hoof could be made the next step was to see if damages in the hoof could be detected. These damages had to be created since the hooves that were available were healthy. The damages were made to simulate different hoof injuries. This is decribed in the Methods chapter in section 2.3.

Empty cavity

In section 3.3.1 of the Results chapter figure 3.6 shows a comparison between the average for the undamaged hoof and the average for the hoof with an air filled cavity. (This cavity can be seen in the picture in figure 2.3). Both curves are horisontal for a while before they deviate from the horisontal line. The difference between them is that the one corresponding to the cavity deviates before the one corresponding to the undamaged hoof. The curve decreases which means the thermal conductivity is getting successivly lower. Since air conducts heat badly it is the measurement reaching the end of the hoof material and the start of the air that causes the decline. Since the curve corresponding to the cavity decreases sooner it is reaching the air sooner which would be expected since the cavity is filled with air. It is therefore clear to see that an air or gas–filled cavity can be detected using this method. The measurements also give information on how deep into the hoof the cavity is situated. In figure 3.7 curves have been fitted to the averages to show the relationship between the two curves more clearly.

Cavity filled with foil

Since abcesses in the hoof are most often filled with something that is not air a set of measurements where carried out where aluminium foil acted as a substance present in a cavity. More about how these measurements where set up can be seen in the Methods chapter in section 2.3.2.

The results of these measurements were compared to the results for the undamaged hoof and for the hoof with the empty air filled cavity above. The graph in figure 3.8 shows all three cases. As was described in the last section it can be seen that the curve for the air filled cavity deviates sooner than the curve for the undamaged hoof. The curve for the foil filled cavity has a different behaviour though. At the start it is horisontal like the others but before it declines the thermal conductivity rises. This is due to the fact that aluminium foil has a higher thermal conductivity than the hoof material and air. Since this can be seen for an aluminium foil filled cavity it should be possible to detect an abcess in the hoof. Obviously abcesses in hooves are never filled with foil but they are, like the foil filled cavity, a cavity containing something that has a different thermal conductivity than the hoof itself. For that reason, for every sort of abcess, the measurement curve should first correspond to the hoof and then change at the probing depth where the abscess ocurrs. At the depth of the abcess the thermal conductivity should correspond to the substance inside the abcess and after that go back to the λ value of the hoof or that of the lamellar layer or of the blood flow in the hoof. In the case of the dead hoof the curve declines after the foil since it is reaching the air inside the hoof. The values for the thermal conductivity in the graphs are calculated from temperature measurements done by the sensor and are dependent on what value for the specific heat (at constant pressure) C_p is given to the software before calculations are made. The value put in for these calculations corresponds to that of the hoof which is very different from that of foil and air. This means that the values for λ is not totally correct but the trends in the curve is still accurate for materials different than the hoof.

4.2.1 Hoof with a growth

The idea of simulating a growth is to be able to diagnose keratomas which are very hard to diagnose at the moment. It is also hard to know the size of them. The keratoma is a tumor built up of hoof-like material. More about keratomas can be found in section 1.1.1 in the Introduction chapter.

To mimc a keratoma a ball of blu-tack was attached to the inside of the hoof. How this was done can be read in section 2.3.3 in the Methods chapter.

The result of these measurements can be seen in figure 3.13, where the green curve represents the hoof with a growth on the inside and the pink one corresponds to the hoof without a growth. Both curves are avarages of seven measurements taken at the same place on the hoof. The two curves start to decrease at roughly the same probing depth but the green curve decreases at a different, slightly slower, rate. This indicates that different materials have been reached at the point of the decline. For the pink curve it is air that has been reached since there is no growth in these measurements. For the green curve there is something different that has been reached. It does not have the same thermal conductivity as air or the hoof itself. This is what is to be expected since the blu–tack is reached instead of air or hoof material. As for the foil filled cavity above the λ values are not exact for the blu–tack since its C_p is different to the C_p of the material in the hoof. The exact values are not of great importance since it is only necessary to show that there is something foreign in the hoof to make a diagnosis. If the exact values were to be found a calculation method that does not assume the same C_p for all the values in a measurement has to be used.

4.3 Living horses

During the measurements on real horses some reflections arose on how to improve the data. Some improvments could be achieved by changing the methods.

4.3.1 The measurement

The instrument calculates the temperature drift in the hoof for about 40 seconds before the real measurement begins. This is very important in a dead material to establish that enough time has went by since the material was last heated either by handeling it or by measurements. If there is a temperature drift this can be compensated for in the in the calculations. Since a horses hoof heats or cools when the blood flow changes, the temperature drift does not have to be linear as in the case where a dead material adjusts to the surrounding temperature. For this reason the temperatur drift is not so interesting and only adds time to the measurement. Since time is of great importance when dealing with horses, who are reluctant to stand still, it could be good to shorten the time for the drift measurement or cut it out entierly.

4.3.2 Handling the horse

To hinder the horse from shifting its weight around between its hooves a pedistal can be used. We saw that the measurements with the least surface supporting the hoof from underneath the better the measurments seemed to turn out. Even if the horse moved slightly when the hoof was suspended it did not signify as much as when the hoof was standing on the ground.

4.4 Conclusion

It is possible to make reproducible measurements with good accuracy on dead hooves in the lab. This can not yet be established for live horses with the measurements gotten this far. It is also possible to show defects in dead hooves with this method.

An air filled cavity as well as a foil filled cavity can be detected and identified. A growth made of a foreign material to the hoof can also be detected.

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