MASTER'S THESIS

Circular Saw Inspection System and Sawing Accuracy

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CIRCULAR SAW INSPECTION SYSTEM AND SAWING ACCURACY

Abstract

The goal with this work, which extend over a period of 3 years, is to create a tool/tools that can help sawdoctors perform better. This thesis covers the first five months and was made year 1999 at Forest Research Institute, Rotorua New Zeeland. It contains of a Literature review, what features to measure and how this affect a sawblades performance, building and evaluating of the first prototypes. The thesis also include a test of a statistical method in order to measure every sawblades individual performance.

Two prototypes were constructed which measure five features:

> A video inspection system that measures every tooth individual side clearence angle and tip width.
> A system for measuring a sawblades individual topography
> Two systems for measuring sawblades tension (light gap and naturalfrequency).

The video inspections system have a precision in measuring the side clearance angle of 0.56 degree average standard deviation and tip width precision of 0.14 mm average standard deviation. Better precision in measuring side clearance must be made and can be achived with higher resolution in camera and bigger monitor.

First prototype aimed to measure a sawblades individual topography and tension at the same time. As a result the blade was mounted on a hub horizontally. Unfortunately result showed that sawblades topography became inconsistent. The sawblade has to be mounted vertically to prevent effects from gravity. A new prototype was constructed but could not be evaluated due to an accident when transporting the prototype to the mill.

The tension was measured in two ways: by light gap method and measuring a blades natural frequency. Measuring the tension by its natural frequency was more of a test in order to determine if this could be an adequate method. An accelerometer was used to create a pulse into the blade. The evaluation showed that it was hard to tune in the right frequency which is crucial for a consistent result. One way to get around this problem would be to send a number a frequency in to the blade (pink noise) and record all naturalfrequencies.

To eliminate effects of lumps the light gap method was performed on new sawblades. Each blade was mounted horizontally on a hub and fixed at a point in the rim. A bending force was performed on the opposite side of the fixed point and the light gap was measured on a 90 degree angle from the fixed point and the bending force. The result showed inconsistent readings. Up to 1.92mm difference in light gap on the same sawblade was measured. Next step is to perform the test again but now redesign the prototype so that the blade is being mounted vertically.

A Mathematical method was created and tested which aimed to calculate sawblades individual performance by knowing the boards position in the saw and by measuring the boards thickness (variance) in a number of points. Result show negative variance on a number of sawblades which is mathematically impossible. The conclusion is therefore that this mathematical method for measuring the blades performance can not be made.

1. Introduction

The performance of a sawmill or other types of production will always be a matter of how efficient every single link in the total production chain is. In a sawmill, one of these links is the work done by the sawdoctors. One of the main goals for the sawdoctors is to keep the circular sawblade in such a good condition in order to produce a small and straight sawkerf as possible. To reach this accuracy suitable tools, measuring methods and devices among other things are needed. In a circular sawblade, many parameters can be very difficult to measure and therefore it is quite common that sawmills have insufficient measuring devices and methods.

The goal with this study is to come up with a proper tool/tools which can help these sawdoctors to perform better and more accurate results. The project extends over a three years period and this report covers the first five months. The report contains:

- Literatures review about what kind of parameters to measure and if data is available how much these parameters effect the sawkerf.
- A methodology that covers the design of the circular saw inspection system but also the design of a mathematical method that calculates each sawblade’s individual performance while running.
- Results from two different tests concerning the device reliability in the stage of development.
- Results from tests concerning a mathematical method that calculates each sawblade’s deviation while cutting.
- Production of the circular saw inspection system.

2. Literature review

A whole lot of material has been reviewed and this constitutes the base for this research. Lets start from the beginning and look at the factors that are of significant interest and what kind of effects it has on the sawkerf. This research is made upon a modern circular gang saw with spline arbour and thin circular sawblades.

What parameters to measure and how much do they effect the sawkerf?

There are mainly three parameters that causes the whole problem and these are:

- Heat or actually difference in heat.
- Vibrations due to disturbance forces.
- Individual deviations of the teeth.

One way of dealing with these problems will logically be to construct sawblades that decrease these three factors. This literature review lists the sawblades parameters that are of main interest for this research and also to explain the effects they have. Furthermore, it also gives a review of available test, if any, how much they effect the sawkerf and measurement accuracy.

2.1 Cutting edge

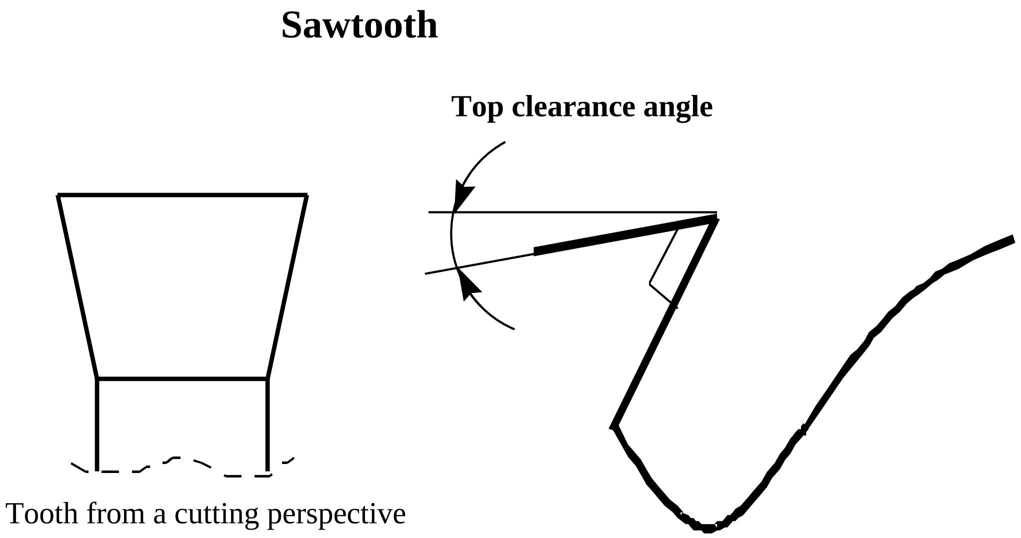

Fig.1. Conventional straight edge saw tooth.

The actual cutting edge plays a significant roll for the behaviour of the entire sawblade. Looking on a conventional straight edge saw tooth, fig.1, fibres tend to be chopped off with a high force of impact. If a tooth is damage in some way a more tearing performance will certainly occur. A higher degree of heat emission and disturbing forces will be present and this will lead to the fact that a bigger sawkerf are being produced.

When a saw tooth cuts wood a certain amount of force is applied to the wood causing local deformation. Immediately after the cut, a ”rebound” of the wood occurs. To avoid heat extraction, due to friction from the rebounced wood and the tooth, a top clearance angle is introduced, fig.1. Here it is important that this angle is right in size. If the angle is too small the material of the tooth will increase which effected the endurance in a positive way but will not exclude the friction that takes place. If the angle is too big material of the tooth will decrease and the cutting wedge will be too weak. Weaknesses like this will effect the edge and make it dull much faster.

Kirbach states in his technical report (*Thin-kerf sawing: how to make it work*) that the top clearance angle on circular- as well as band saws should never be larger than 10 degrees to perform maximum.

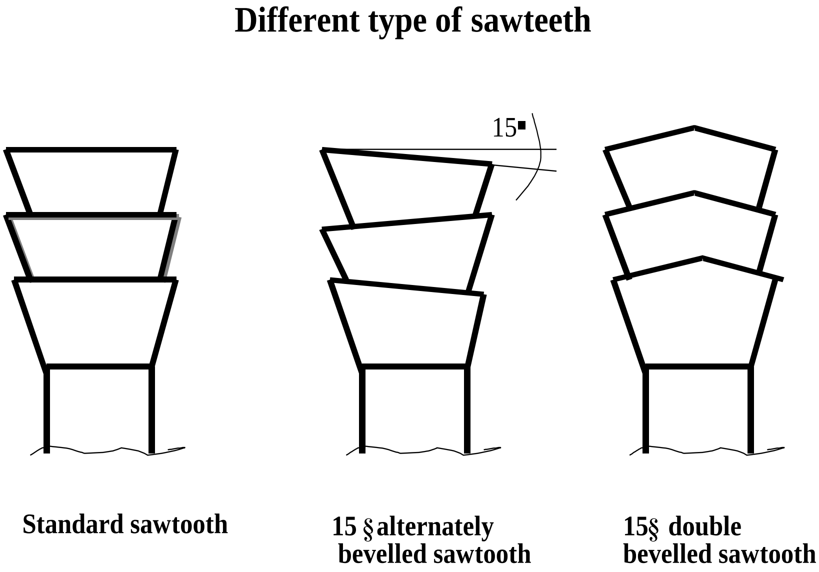

Fig.2. Different saw teeth seen from a cutting perspective.

The figure above shows that a new technique for cutting has been developed. The method is called “bevelling” and is a method which tries to reduce the cutting forces by introducing a cutting angle on the teeth, see fig 2. Instead of a more traditional chopping off a fibre a gentler cutting will take place. According to Kirbach and Sykes (*1993*) an introduction of a 15 degrees bevelled saw tooth will increase the performance with:

1. a superior cutting accuracy of 0.3 mm standard deviations.
2. significant drop in power consumption.
3. better quality on sawdust used as a fibre source.
4. washboard problem is eliminated.
5. stalling problems with marginally power gang edges are eliminated.
6. problems in transporting chips in conveyors are reduced.
7. congestion at chip screening caused by the formation of ribbons is significantly reduced.

2.2 Side clearance angle

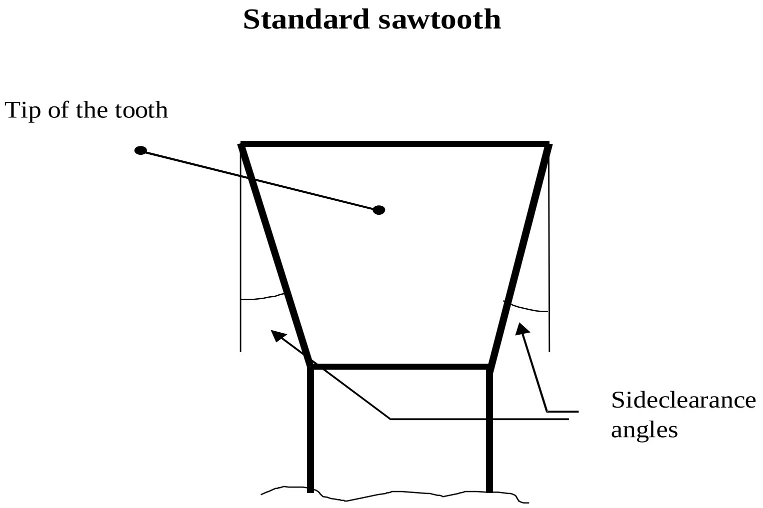

Fig 3. Tooth seen from a cutting perspective.

Another very important factor is side clearance angle, see fig 3. Its function is to prevent the blade from getting in contact with the wood. Kirbach and Sykes (*1993*) have proved that the side clearance angle should be at least 3º in order to give an optimal performance. But Kirbach also states that differences in moisture contents, frozen or unfrozen state, stresses in the wood and that wood density will have an effect on the right size of the side clearance angle. The size of the angle shall therefore be taken more as a recommendation than as a fixed truth.

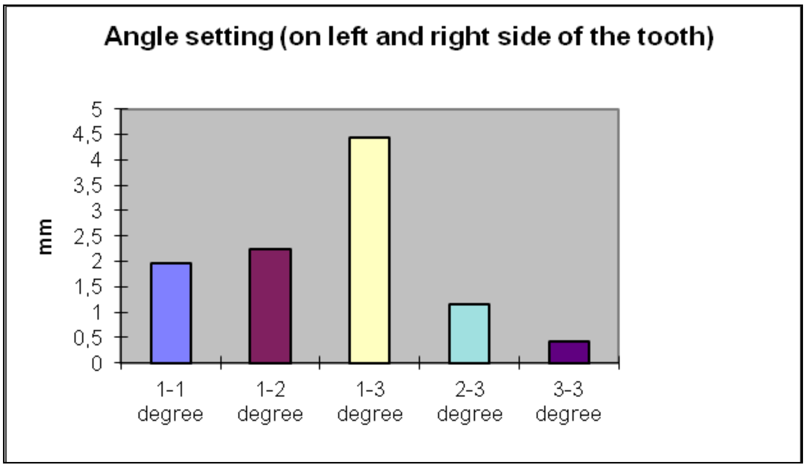

Fig.4. Effect on sawkerf with inaccuracy in the grinder.

The figure above shows the most important thing with the side clearance angle and that is the need for precision from the grinder, the machine that produces it. A difference in precision, between left and right sideclearanceangle of 2 degree can cause an error of **4mm standard deviation**! on the sawkerf with blade diameter of 590mm, see fig 4.

2.3 Gullet area

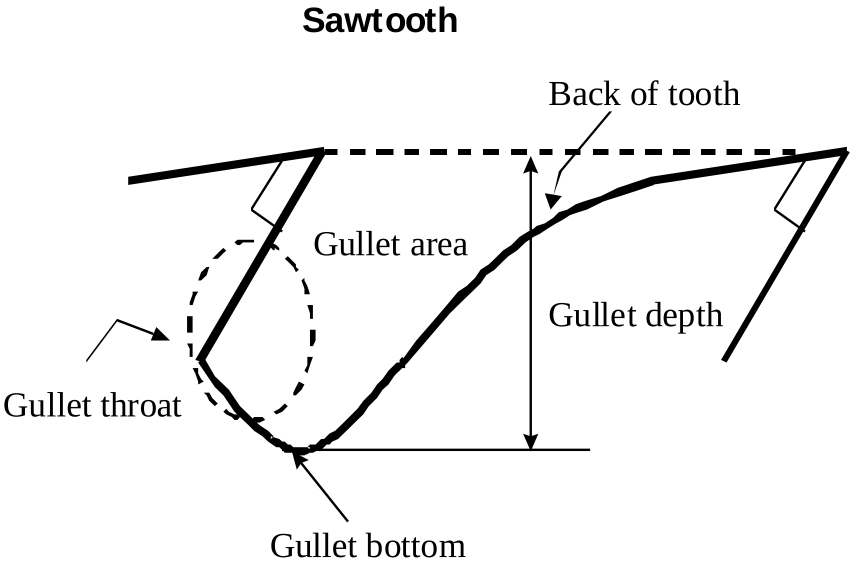

Fig 5. Sawtooth from a circular sawblade.

It seems obvious that the gullet area and design of the saw tooth is of significant interest, see fig 5. If for example a too small gullet area is produced or if sawdust refuses to leave the gullet the results would inevitable be that the pressure would be to high and the only way to release this pressure is by leaking sawdust between blade and wood. If this happens sawkerf will definitely increase. Old studies, produced on bandsaws, claims that 70 % of the gullet area can be filled before sawkerf error gets excessive. However, and this is very important, studies have recently been executed which indicates that thinner circular blades need a bigger gullet area than the suggested 70%. Laboratory test performed by Kirbach states that sawing accuracy decreases already with gullet fillings of 30 %!

So, why not then produce an over sized gullet area in order to get away from the problem with to much sawdust in the gullet. Well, there is a problem with that issue and it concerns the stiffness requirements of the tooth. If a gullet is made to big instability of the tooth can occur with a bigger sawkerf. However a way to increase stability is to make the back of the tooth longer and in this way achieve a more stable tooth, see fig. 5.

Gullet dept and gullet throat is other important factors, fig. 5. The size of the gullet dept and the throat depend entirely on what kind of density the wood contains. Higher density species require a much shallower gullet and a shorter gullet throat than lower density species.

If the gullet bottom does not expose flatness, damage normally due to friction, lesser pressure can be obtained with sawdust leaking as a result. Keep therefore bottom in a good condition.

2.4 Sawblade tension.

When a blade starts to cut the log into boards a force is applied which immediately causes a vibration in the blade. The vibration can figuratively be compared with a stone, which is thrown into a lake causing circles on the surface.

Disturbance force effect when impact.

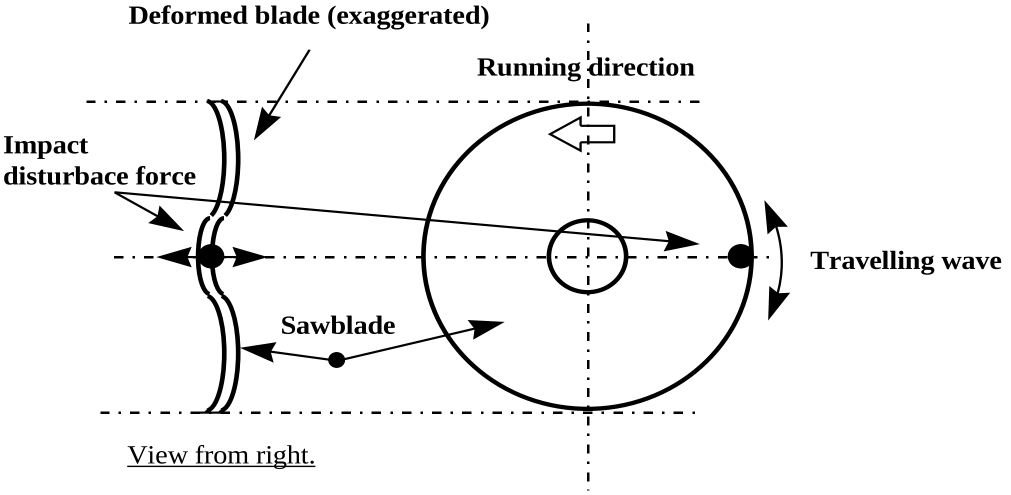

Fig 6. Effect on sawblade while running.

From a blade’s point of view, the force is creating a sinusoidal wave that runs both clockwise and counter-clockwise around the blades cutting direction, see fig. 6. The wave that runs counter-clockwise is the one that causes problem. What happens is that the wave decreases the natural frequency of the blade, while the running speed increases, and if the running speed is too high, the natural frequency will drop down to zero. At this point, unstable resonance condition occurs which easily can deform the blade in certain ways. This state is called ***critical speed.*** In the critical speed state, a standing transverse wave pattern is performed which results in the fact that a small disturbing force causes a snaking of the blade. In other words, the actual sawkerf increases and that in its turn leads to final products with errors like wedge, thickness and width variances.

Wave patterns in sawblade.

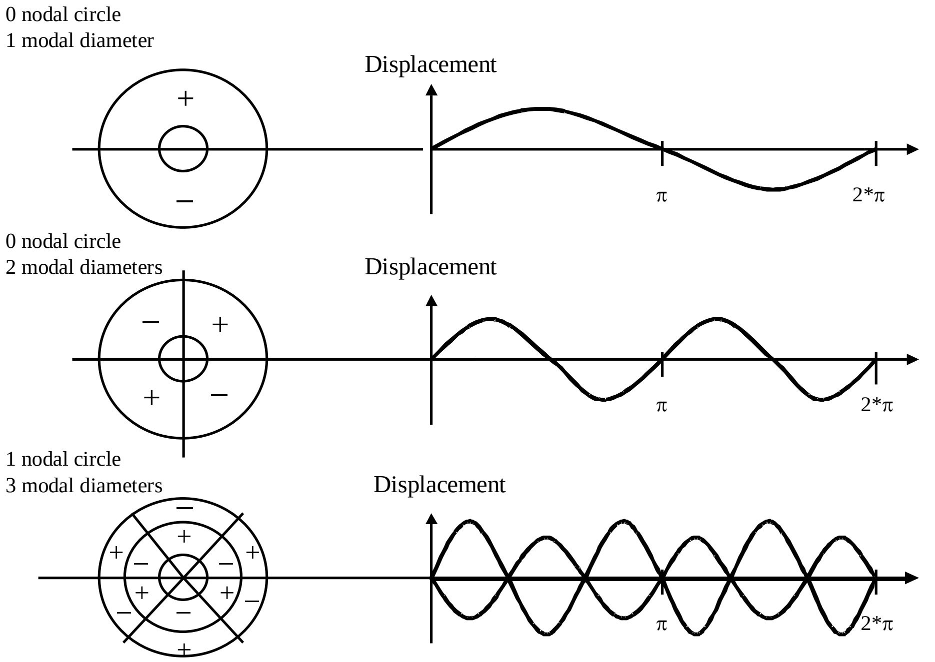

Fig.7. Wave pattern from different nodal and modal diameters.

A blade has more than one critical speed state. Each state shows a different wave pattern and can be described with different numbers of nodal- and modal diameters, see fig. 7. Nodal and modal points on the saw can be defined by the fact that they show zero displacement while they are oscillating. If fine-grained sand is placed on the blade’s surface a wave pattern will be produced that displays the different nodal and modal shapes. It is the constituent of the blade that sets the rules of what critical speed to be aware of. Critical speed of main interest is the one that appears first. It is the factor that control how high operational speed that can be used. Normally, this happens in the second, third or forth nodal diameter modes. Where this nodal or modal diameter occurs can be determined by recording where the blade’s natural frequency peaks are situated. This means that to know a blade’s **natural frequency** helps us to get information over the sawblades performance.

2.4.1 What is natural frequency?

Everything has a natural frequency for instance a guitar. When a force is applied to a string a sound develops. This sound does only changes in strength when the force varies. The frequency of this sound is the same as that strings natural frequency. If the tension in the string increases a higher sound will be heard due to higher natural frequency and a direct relationship between tension and natural frequency can therefore be established.

An object has always more than one natural frequency. Each frequency experiences different number of nodes and modes. By studying in what frequency each nodes and modes occurs and compare that information with the working conditions of the sawblade. The certain node and mode to be aware off can be established. Fig. 7 shows the first tree natural frequencies and its set of nodal and modal wave patterns.

2.4.2 How to change the natural frequency and to what extent?

Natural frequency of a sawblade shares the same physical rule as a guitar. However due to a difference in geometry, a harsher working condition (normally) and the fact that it is spinning gives it a much more heterogeneous tension pattern.

When a blade spins forces of central gravity tend to drag the blade into a bigger diameter. Since the rim expands more than the eye higher tension will therefore be present in the rim.

Another phenomena that normally play a much more significant role for a blade’s tension pattern is heat propagation or actually difference in heat. Heat propagation, which occurs from the friction between blade and wood, will work in the opposite way than the central gravity. Heat expands the material and since there will always be a difference in temperature between rim and eye, stress differences will take place. In order to get a good tension profile in the sawblade, considerations of both central gravity and heat propagation must be taken into account.

One way of changing the natural frequency and therefore increase the critical speed is by **pre-tension**. The idea is built upon a controlled deformation of the blade and is made by expanding the inner area and letting the rim stay untouched. When so the heat expansion starts the blade’s rim is allowed to expand a little bit more. If the blade is allowed to run with the same speed a more stable blade will be present.

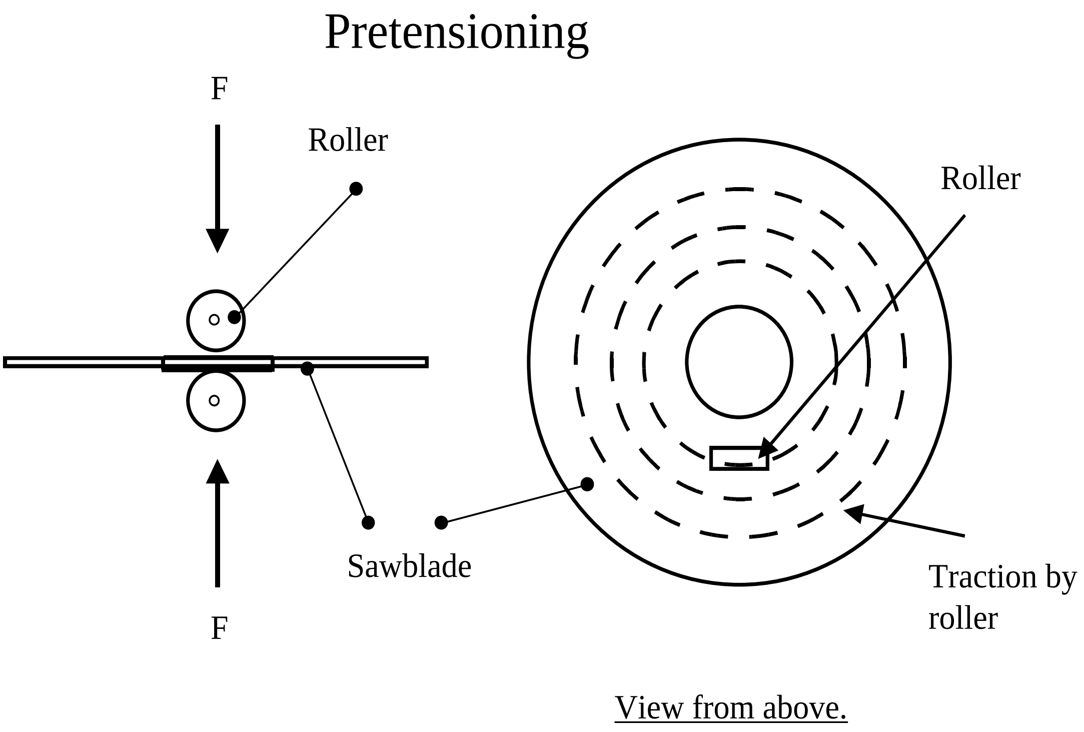

Fig.8. How pre-tensioning is executed in general.

Pre-tensioning is practically executed as follows; a force is applied on the surface of the sawblade, fig 8, and rolled on a certain radius around the blade. The more tracks there are on the blade the bigger is the deformation and the higher becomes the tension. How big force and how many tracks that are needed, depend entirely on what kind of material (stiffness, hardness etc.) and the thickness that the blade exposes. Instead of using rollers, the same procedure can be executed by the use of a hammer.

Moreover, if the tension is changed too much, it will unfortunately also effect the sawing performance. The thing that happens is that the tension in the rim gets too high in other words the rim gets too small and dishing of the blade will occur. Making the rim bigger by rolling in tension close to the teeth can treat too much tension in the blade.

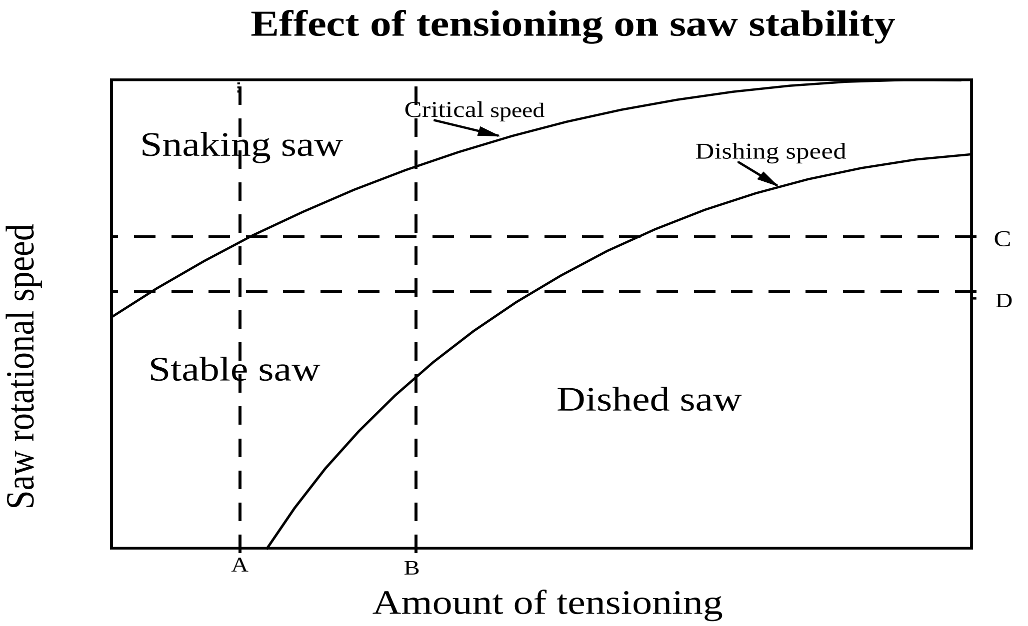

Fig.9. How a sawblade should be tensioned**.**

What is the ideal amount of tension in a blade? According to *Schajer's (1992)* technical report, fig 9, a proper tensioned blade should be slightly dished when it is not running, line B. During the time while it is running central gravity will expand the rim enough to make it flat. Compare crossing point A-D with B-C in figure 9.

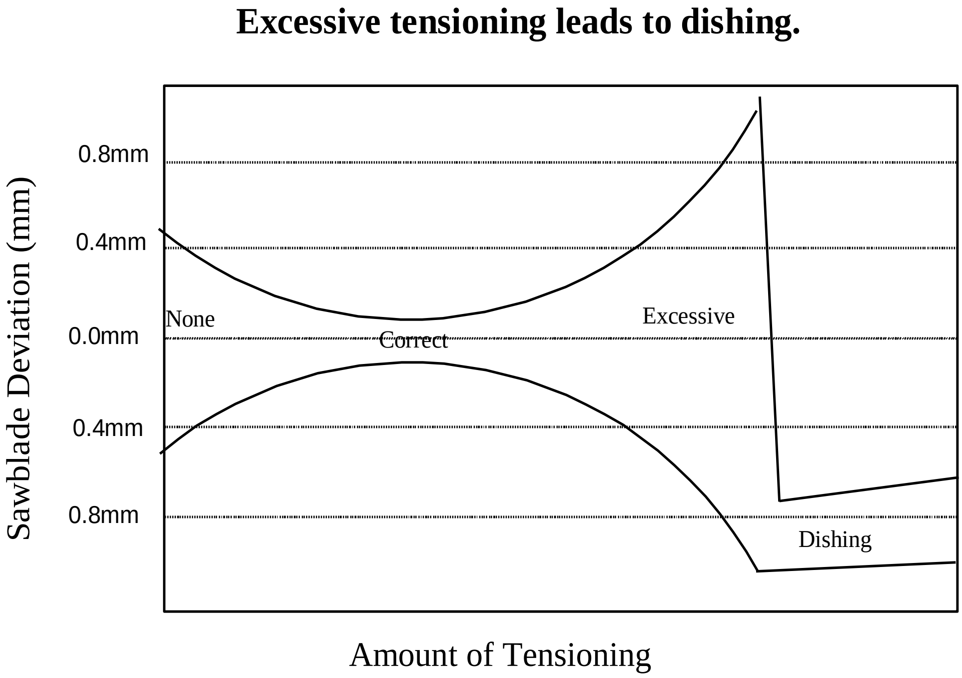

Fig.10. Test on sawkerf made by different kind of tensions in the blade.

Another way of looking at a correctly tensioned blade is to see how it actually performs. According to tests done by *Mote, Schajer and Holøyen(1989),* wrong pre-tension can cause a deviation difference on sawkerf by a **factor of 9**, see fig 10. Holding the right amount of tension in the blade saves a whole lot of log and hence money.

2.4.3 How can tension be measured?

Berolzheimer claims in his study (*1989*) that when tension is rolled into the blade the frequency peaks from the different nodes- and modes diameters tends to drift apart. The nodes of interest (critical speed node) will be showing a higher frequency than before tensioning. If a “perfect” blades peaks can be identified conditions could be set and used as a guideline. Where optimum lies depends totally on the constituent of the measured blade (thickness, hardness, size etc.) and must therefore be proved for every type of blades.

Another method for measuring tension is the **light gap method.** Schajer (*1992*) describes that method as follows.

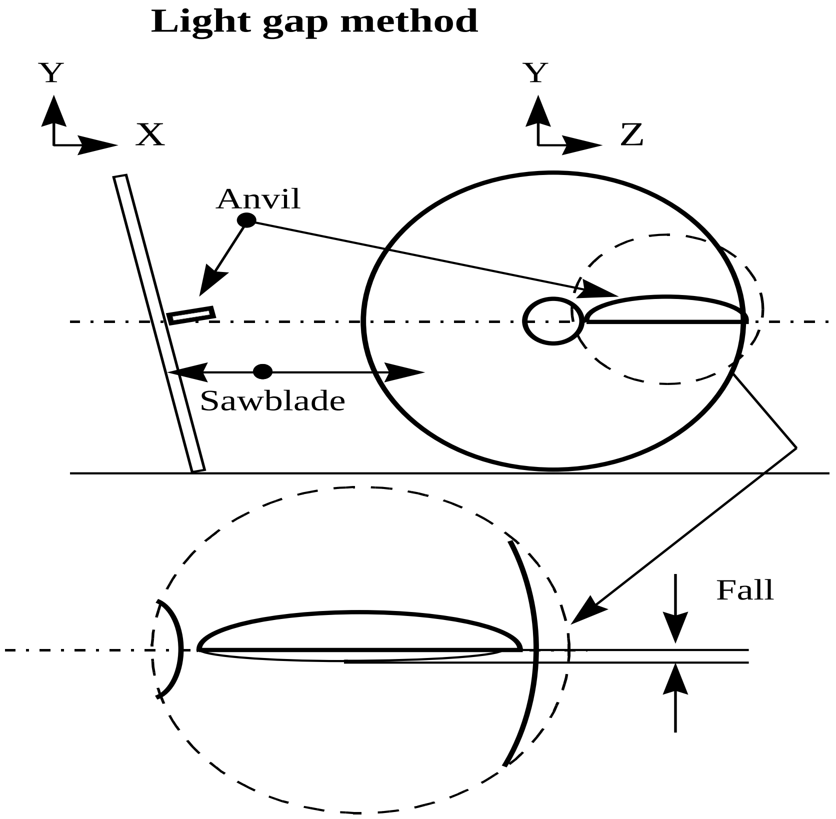

Fig.11. The light gap method.

The light gap method can be produced in two different ways but builds on the same physical appearance. One way of doing it is to lean the blade while holding it. Due to gravity, the blade will be slightly bent. If a ruler is placed across the surface, see fig 11, a difference in the light gap between the rim and the eye will occur due to different contribution in tension. This light gap is called fall and by measuring the size of that fall tension can be determined.

An other way of performing the test is to fix a point in the rim, while an anvil is placed at the eye. By slightly bending the blade over the anvil, opposite from the fixed point, a rise will occur between the rim and the eye. By measuring the rise tension can be determined.

2.5 Lumps, ridges and dishing

If the blade shows irregularities like lumps, ridges or dishing the performance of the sawblade will definitely be effected. Before a blade gets its tension levelling is done. Levelling is, like the name tells, a method that tries to make a blade as flat (level) as possible. An important factor will consequently be to locate where these irregularities are situated. In order to do this the blade is held vertically, without any interference from gravity, and a straight edge held against it. If there are irregularities present, light gaps between the blade and the straight edge will occur and depending on lightgaps formation errors like lumps, ridges or dishing can be located.

When an irregularity is spotted, adequate methods to level it out can be taken into account. If an irregularity consist of a lump or a ridge material is moved from neighbouring areas by plasticising the blade. Plasticising is performed in such a way that tension is rolled or hammered into the blade how it is performed can be seen in fig.8. However, if dishing is the problem the rim is made bigger by rolling in tension close to the rim.

3. Methodology

After a lot of studying it was now time to start designing and building the saw inspection system. The work is divided up into four sub goals:

1. to produce a method for measuring the sawblade’s topography.
2. to produce a method for measuring the sawblade’s tension.
3. to produce a video inspection system.
4. to produce a method for measuring a circular sawblades individual performance.

Starting with sub goal number one.

3.1 Sawblade’s topography.

The idea of this method is to capture the distance between a number of fixed points, in space, and the sawblade’s surface. By recording the magnetism in the fixed points an approximate topography can be established, see fig.12.

The sawblade was located on a horizontally aligned and rotating hub. To measure the magnetism (distance) in a number of fixed points five analogue sensors with a range of 6 mm were used. The sensors were placed on bar, 25 mm from each other and 3 mm above the surface of the blade. The bar was then placed horizontally above the sawblade and in a straight line over the centre of the blade. In order to record the surface in a number of points, a device that triggers the analogue sensors are needed. An inductive sensor was also added to the design and was placed above the teeth. This kind of sensor is ”event based”, which means that it can only deliver a 1 or a 0. When the hub and the sawblade are put in motion a tooth will pass recording an ”event” with a triggering of data as a result. The inductive sensor can be adjusted to deliver one or two pulses a tooth. The layout has following looks:

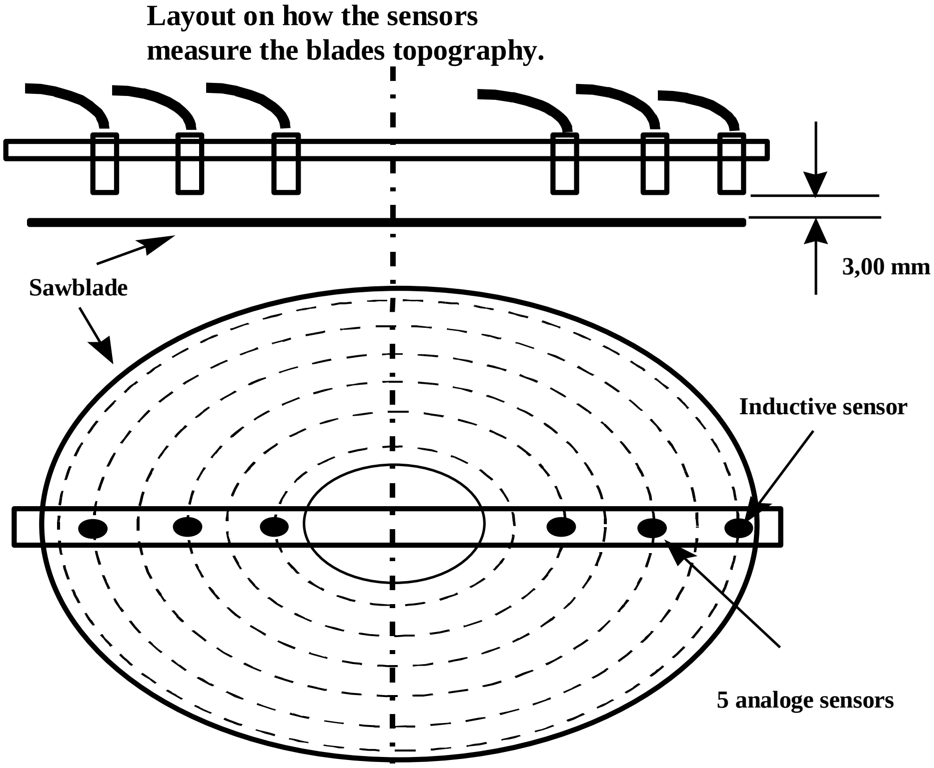

Fig.12. The position of the sensors.

The information from the five analogue sensors was displayed with a PC, LABview software and a data acquisition card. Five lines on a certain distance from the sawblade’s centre, see fig 12, that approximate the blades total topography can be presented. In order to run the sensors, a DC power supply was needed and attached to the design. Prototype one was completed.

The next step was to calibrate the sensors. It was carried out by putting a perfectly aligned metal bar in front of the sensors and manually adjust them to the same output signal. The size of the signal should be set in the middle of the sensor’s measuring ranged and in this case that distance was 3 mm. Differences in material between the sawblade and the calibrated bar will cause a difference in the output signal (due to difference in magnetism). Therefore, it is important that the bar, which is used for calibration, has the same material and thickness as the sawblade. If not, adjustments must be made for the difference.

3.1.1 How to analyse the recorded topography?

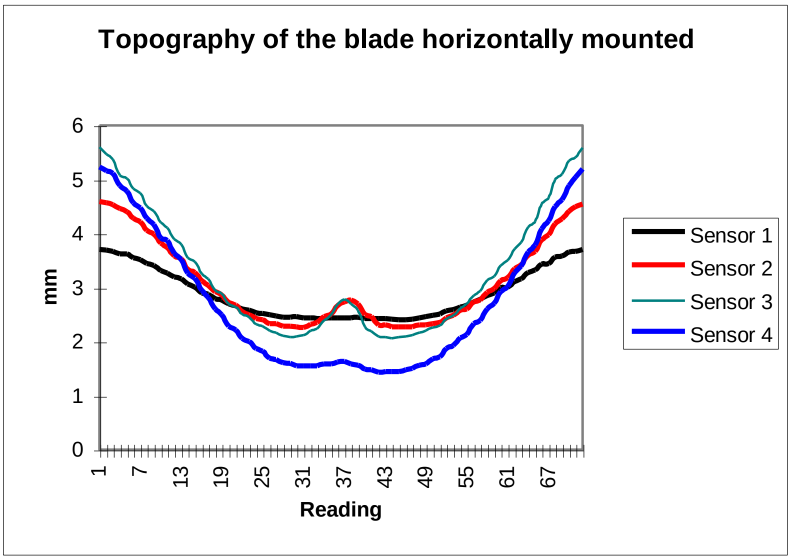

Fig.13. Displayed topography of a horizontally mounted sawblade.

A sawblade was placed on the hub and put in motion. Four lines were captured in 72 points around the blade and analysed, which corresponds with a tooth taken twice. In this case, due to a smaller sawblade, only 4 lines were used, see fig.13. If the topography that can be seen in fig.13 is the true topography will be seen in the result section. What information that can be collected from fig.13 and how to present it can be seen in the next chapter and it is called the curve evaluation.

3.1.2 Curve evaluation

When the topography was captured each sensor recorded a line at a certain radius from the sawblade's centre. Curves were produced and an approximate topography over the measured sawblade can be displayed, see fig.13. It is not likely, looking at the graphs, that each sawdoctor make the same interpretations were the different errors starts and stops. To exclude misinterpretation, a mathematical method has been designed which focuses on the symmetry of an error.

Looking at a damaged sawblade in a cutting perspective and spin it, a snaking performance occurs. A concave lump always follows by a convex lump or vice versa. When these errors are levelled out, a strait sawblade will be produced. If the shifting points from concavity to convexity or vice versa can be localised misinterpretations would be eliminated.

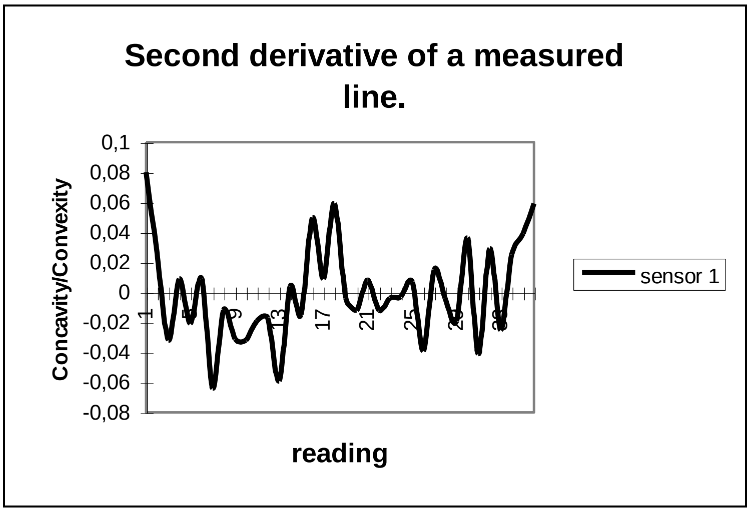

Fig.14. Second derivative over a line measured by sensor 1.

To deal with concavity and convexity in a theoretical sense, means to analyse the second derivative of a line. Applying the second derivative on a measured line with one reading a tooth gives us figure 14, see above. Sometimes, a small local defect can cause a big shift in the second derivative. The readings can be smaller cavities on the surface or irregularities like background vibrations. In any case the effects on the sawing performance will be minimal.

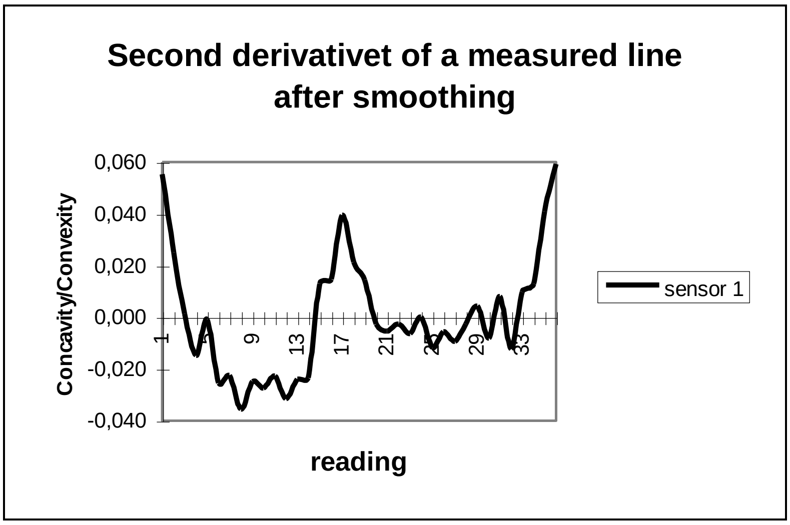

Fig.15. Second derivative of a line, but this time after smoothing.

To exclude irregularities like cavities and background vibrations a method has been developed and it is called smoothing. Smoothing is a method that is applied on the measured line and works like a mean value filter. The method replaces a measured point with a calculated point by taking an average of the nearby points.

The effects can be seen in fig.15 and is the same second derivative as in fig.14 but has now undergone smoothing. It is now much easier to see where lumps/bends start and stop. Shifting points can be observed, when the curve cuts x-axis, a mark can be produced on the sawblade and lumps/bends can eventually be treated with a suitable method.

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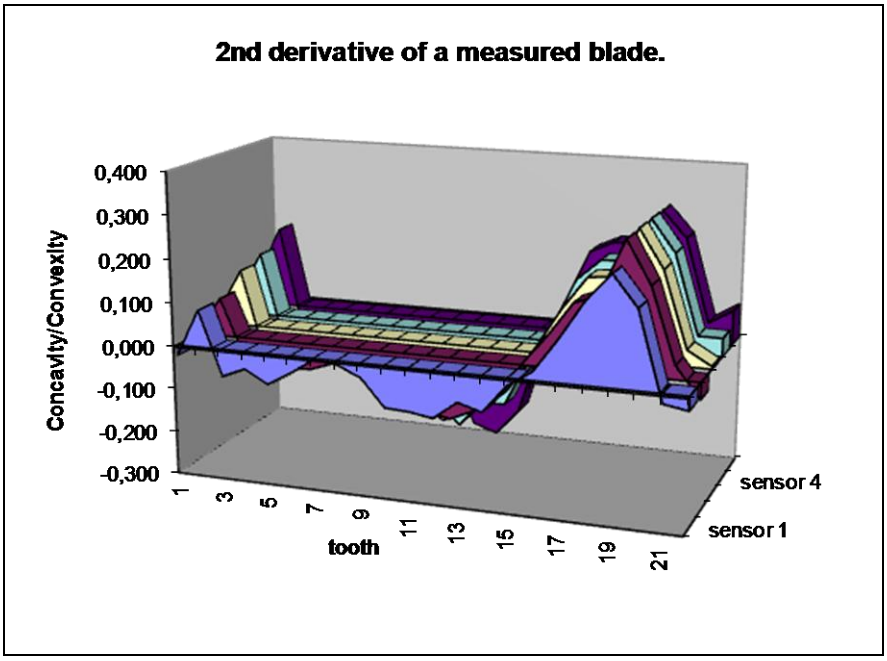


Fig.16. Topography over a blade in a second derivative's point of view.

Looking at all sensors at the same time and with the curve evaluation technique following topography is presented, see fig.16. By making a lot of tests on perfect aligned sawblades the level whether a lump/bend will be levelled out, or left without treatment can be determined. Taking the collected inflection points and apply theme in fig.13 the height of the lump can be determined.

3.2 The sawblade's tension

The approach was to create a system where the tension can be measured by its natural frequency (see literature review section). In order to carry out the approach, low frequencies needs to be captured and the choice fell on a device, named accelerometer. An accelerometer is a device that has the ability to record low frequencies, while it is lying on a vibrating surface. To increase the contact between accelerometer and sawblade a small amount of grease was applied between surfaces.

Since the accelerometer was lying on the sawblade's surface a horizontal capturing method was to be preferred and the same stand and hub, as in the topography design, where used. To isolate disturbances from the hub three silicon washers were placed between the blade and the hub.

The next step was to capture the frequencies the accelerometer was recording. A way of doing this was to use an oscilloscope. Because of the fact that it is a rather expensive apparatus but also because a PC was present a data-logging program with name PICO ADC-12 was used. PICO ADC-12 works exactly as an oscilloscope, but with less sensitivity. To achieve a sufficient signal from the accelerometer an amplifier was needed and was also added to the design.

3.2.1 Self weight test

To just record the natural frequency of the blades **can be** insufficient information for producing the right amount of tension in the sawblade. An additive method was desired and also produced.

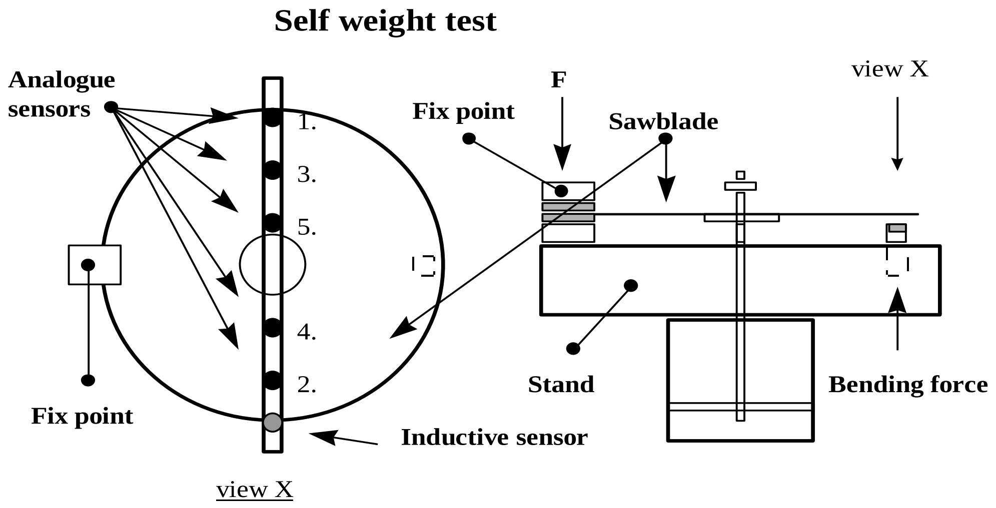


Fig.17. The self-weight test.

The method is trying to copy the self-weight test, (see light gap method literature review section), and was designed in this way. The sawblade’s rim was fixed by applying a force on top of two rubber-coated pieces of wood and the blade (see fig.17). A bending force was applied opposite to the fixed point and the analogue sensors (used in recording the topography of the sawblade) measured the drop. Figure 17 shows a sketch over how the self-weight test is executed.

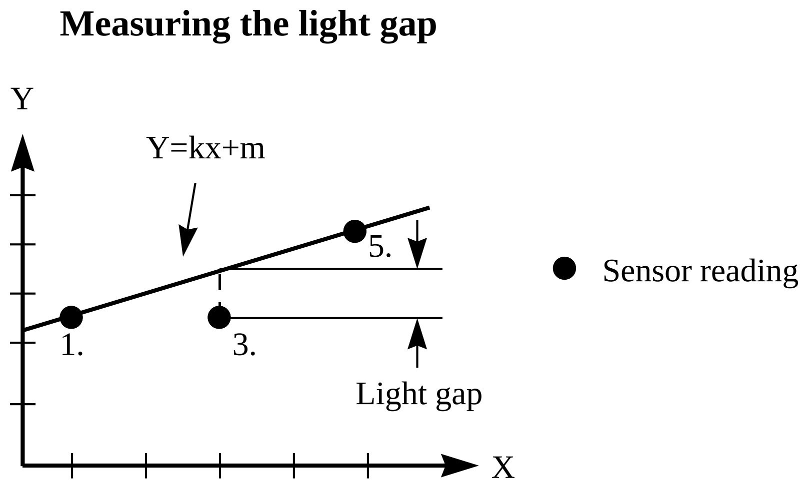


Fig.18. How the light gap is measured.

The light gap was measured by calculating a line through the readings from sensor 1 and 5. By taking the difference between the readings from sensor 3 and the calculated line, the light gap can be determined (see fig. 18).

3.2.2 Testing the tension equipment.

A sawblade was put on the hub and tapped in various places around its rim with the help of a plastic bar. The oscilloscope made the recordings. By setting the oscilloscope to trigger automatically, use a Fast Fourier Transform (FFT) with a Main Timebase (MTB) of 200 ms and CH1 = 10mV~ a sufficient signal was achieved.

It showed that the best signal where found when the accelerometer was placed close to the sawblade's centre and the tapping was executed close to the rim and on the opposite side of the sawblade. The natural frequencies were recorded and captured, (see section 2.4 Sawblade tension). A certain amount of inconsistent reading was proved but instead of excluding the method another method was added.

The new method contains of a pulse generator with variable frequency, which the blades natural frequency can be traced and a more ”pure” signal can be achieved. Adding a 24 V electromagnetic pulse generator, a power transistor (amplification of 100 times), a power supply of 24V (to run the amplifier) and through that putting a pulse from a frequency generator a new method for producing the natural frequency was created. The strongest signal was achieved when the pulse generator was placed close to the rim of the sawblade and recordings with the accelerometer were made opposite to the pulse generator and close to the eye.

The plan was to try the use of a cheaper frequency recorder the PICO ADC-12. The test showed that by using exactly the same input as the oscilloscope the frequency peaks can be displayed but if it is sensitive enough will be a question to answer for the result section.

3.3 Video inspection system

The third sub goal focuses on the importance of having the saw teeth in a good condition. The goal was to design a device that could measure the different kinds of cutting angels, edge condition etc. (see section 2.1-2.4) with a high level of accuracy

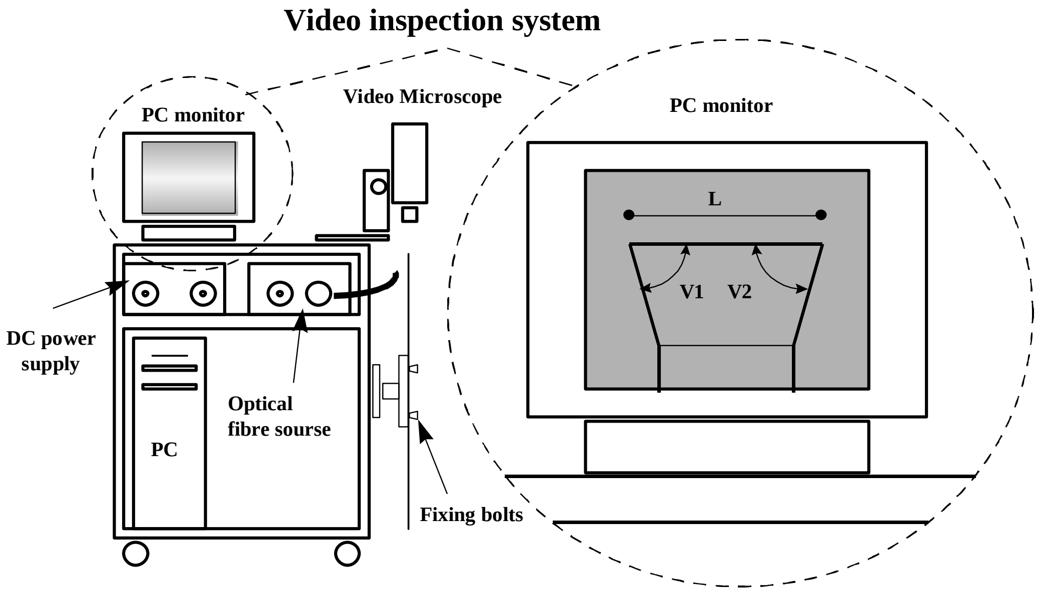


Fig.19. The video inspection system with a displayed saw tooth.

The Video Microscope with a magnification of 100 times was placed above the saw tooth. In order to drive the camera, a DC power supply was added to the design and the captured picture was analysed with a PC and with a Video Trace image processing software. Along with the software, lines can be drawn in the recorded picture and angles/lengths can be measured, (see fig 19). Normal background light showed not to be sufficient enough in order to receive a good picture. A separate optical light source was hence added.

The testing procedure was performed in the following way: A sawblade was put on the vertically placed hub and was fixated by three bolts. An adjustment of the blade was made so that a tooth could be displayed on the monitor. The next step was to increase quality of the displayed picture. The quality of the displayed picture can be increased by adjusting the light, the Video Microscope's stand and lens in a suitable way (made by trial and error). When an acceptable picture was captured, a calibration method was needed so that the actual magnification was shown. By putting a ruler in front of the video lens and by measuring the length in pixels, the actual magnification in pixels/mm was given. After this calibration a correct measurement could take place. The Video Trace software program gives, except for the visual information, an opportunity to measure angles, lengths and runouts with a high level of accuracy (see fig 19).

3.4 Methods for measuring the sawblade's individual performance.

Measure deflection.

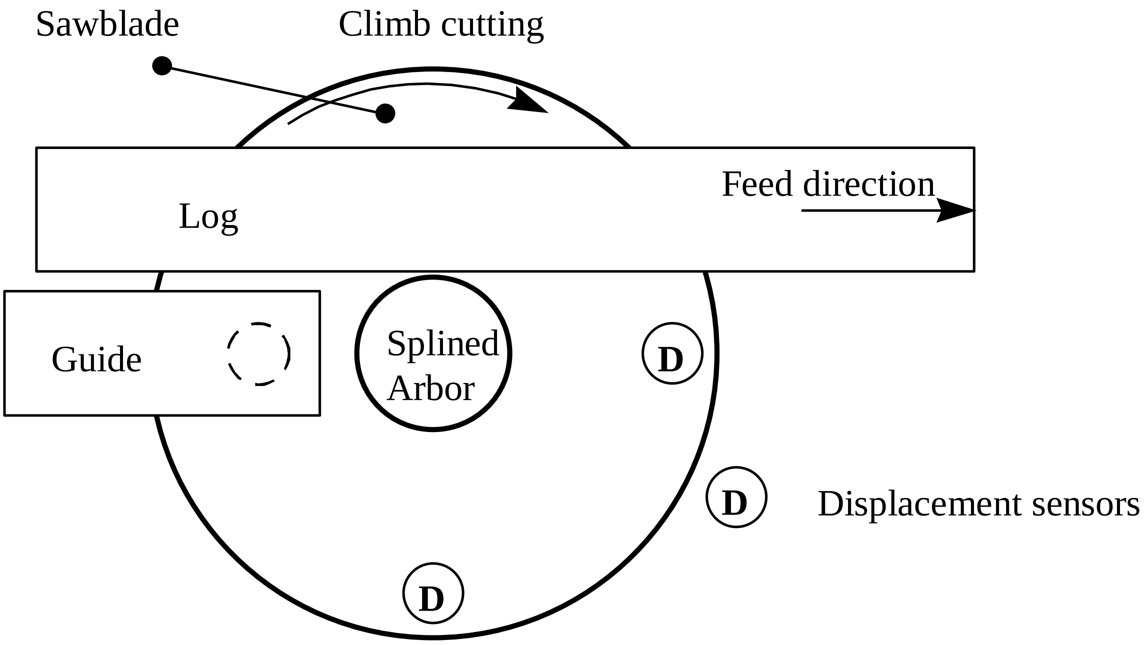
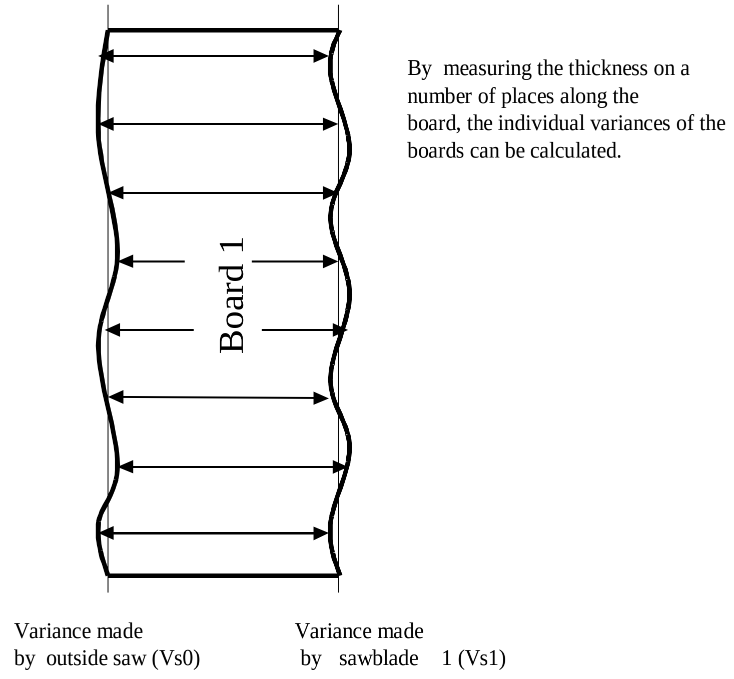


Fig.20. How to measure the sawblade's performance while running.

The normal way of measuring sawblade deviation while running is to use displacement sensors and a recorder placed in the guide. By recording the distance between the displacement sensors and the recorder, deflection of each individual sawblade could be determined (see fig.20). Unfortunately, this method is a rather time consuming operation since the sensors tends to fall off and a simpler and less demanding method to identify deflective saws was therefore required.



By measuring the thickness on a number of places along the board, the individual variances of the boards can be calculated.

Fig 21. How a board is produced.

The method that is developed are based upon the fact that variance from two different sawblades produce a total variance on one board see fig.21. By using this assumption but also the fact that the variance can be measured with good accuracy, a mathematical method can be applied where each and every sawblade's individual performance can be determined (see fig 22).

Statistical method

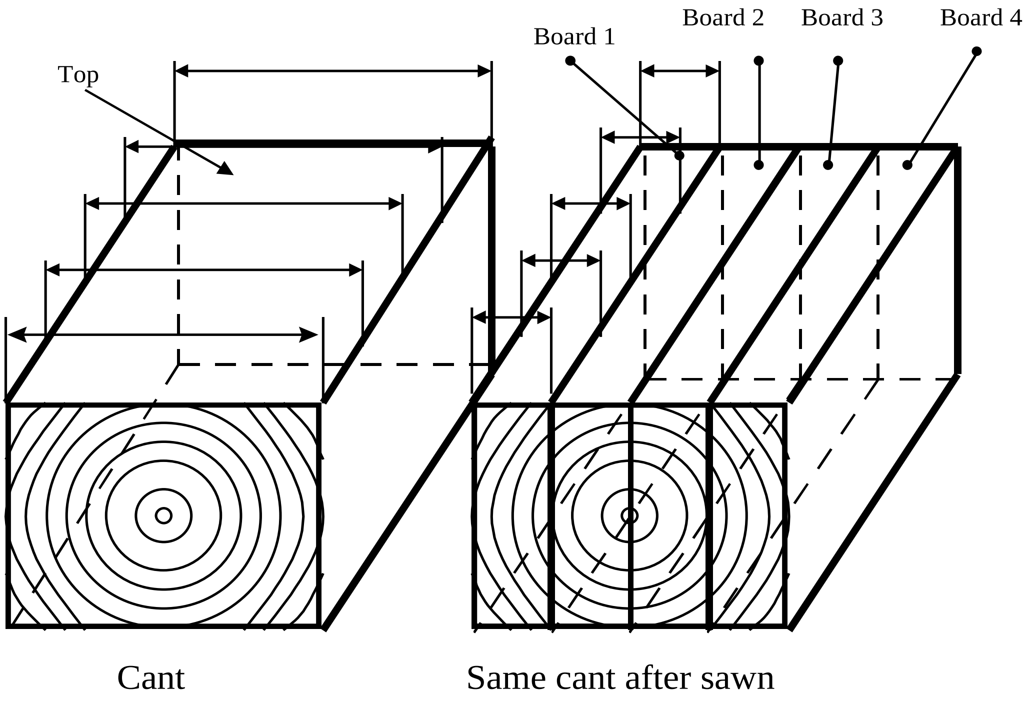


Fig 22. The drawing describes the statistical methods measuring procedure.

By measuring the thickness of the cants and boards, with a slide-calliper, in a number of points along the length, the individual board variance could be calculated. Moreover, by applying the theory that two sawblades produce the total variance on one cant/board following equation system can be produced.

Equation 1:

$Vb1 = Vs0 + Vs1$
$Vb2 = Vs1 + Vs2$
$Vb3 = Vs2 + Vs3$
$Vb4 = Vs3 + Vs4$
$Vcant = Vs0 + Vs4$

Where
Vcant = variance of the cant.
Vb1 = variance of board 1
Vb2 = variance of board 2
Vb3 = variance of board 3
Vb4 = variance of board 4
Vs0 = variance of outside saw (can be a chipperhead)
Vs1 = variance of saw 1
Vs2 = variance of saw 2
Vs3 = variance of saw 3
Vs4 = variance of saw 4 (can be a chipperhead)

The variance on each individual board can be calculated through following equation.

Equation. 2: $\mathbf{Vi = (n * sum(x^2) - (sum(x))^2) / n * (n-1)}$

Vi = variance on a individual board or block
n = number of measured points
x = measured thickness value

By inserting the calculated variances from equation 2 in to equation 1, a solvable system, with five equations and five unknowns, is created. Solving the system following variances on each sawblade is produced.

Equation. 3:

$\mathbf{Vs0 = (Vblock-Vb4-Vb2+Vb3+Vb1)/2}$
$\mathbf{Vs1 = (Vb4+Vb2-Vb3-Vb1+Vblock)/2}$
$\mathbf{Vs2 = (Vb2+Vblock+Vb3-Vb4-Vb1)/2}$
$\mathbf{Vs3 = (Vb4+Vb3+Vb1-Vb2-Vblock)/2}$
$\mathbf{Vs4 = (Vb4+Vb2+Vblock-Vb3-Vb1)/2}$

A circular gang saw contains of more the five sawblades. However, independent of how many sawblades that is in action, a solvable equation system can be determined where each sawblade's individual performance is being shown.

Standard deviation (stdev) is a more frequently used method for determines variations. The relations between variance and stdev is:

Equation 4: $\mathbf{stdev = sqrt(variance)}$

4. Results

The evaluation was executed on thin-kerf sawblades with stellite tipped teeth. The diameter 590 mm and 690 mm were used with a number 3 sized splined arbour and the blade's thickness was measured to 4 mm.

The results were collected from two different occasions and served as an evaluation of the device at that stage. The tests were as far as possible executed in a real sawmill environment. By performing the test in a true environment, disturbance factors could be located and taken into consideration.

The results was collected and performed in following way:

1. evaluation of the video inspection system.
2. evaluation of the sawblades topography system.
3. evaluation of the sawblades tension.
4. evaluation of a statistical method for measuring the blades individual performance.

The first evaluation was divided into two visits. The first one went to a sawmill in Napier with the name ***Pan Pacific*** and to a sawblade manufacturer in Rotorua named ***Checkmate***. The goal was, except from an evaluation of the circular saw inspection system, to establish how a newly produced sawblades natural frequency looked like and how much each peak drifted when tension was rolled in to the sawblade. At this stage the tension was measured when the sawblade was mounted horizontally.

Test occasion number two was also divided into two visits. The first study started off at ***Waipa*** sawmill in Rotorua and after that back to the sawmill in Naipier with the name of ***Pan Pacific***. Except for making the normal tests cycle (1-3) an extra test was added. The purpose of this extra test was to determine the blade's individual performance by measuring the produced boards and cants in a certain way. A summary over all the results are presented below.

4.1 Testing the video inspection system.

An evaluation was made and involved how exact the tip width and side clearance angles (left, right) could be measured. The test was performed as described in section 3.3 but with different magnification in each test. Since sawmills normally use more then one type of sawblades an adjustment, according to the pictures quality, needs to be done each time a different sized sawblade is measured. That will normally lead to a difference in magnification between the test occasions, which effects the precision in the readings. The magnification was as a result different between the five tests. The entire test results are presented in Appendix A.

Side clearance angle (deg.)	Tip width (mm)
0,59	0,14

Tab.1. Precision measuring side clearance angle and tip width in average standard deviation.

An error occurred which involves measuring the side clearance angle. When a tooth was captured and lines were drawn, in purpose to decide the side clearance angles size, it was easy to draw the angle too big or too small. Results from the test can be seen in tab.1 and present an average deviation of the measured side clearance angle between the five tests. The average deviation was calculated to **0.59-degree stdev**. A side clearance angle deviation of **1 degree** can cause an increase on sawkerf deviation on up to **8 times** (for more information see section 2.2 side clearance angle). Sufficient accuracy was not achieved.

The error occurs when the angles are drawn in the picture. To minimise the error a bigger screen needs so that a high magnification can be used and angles therefore more accurate can be drawn in the picture.

4.2 Testing sawblades topography system.

To be sure of a sawblades real topography can be harder than it sounds. When a sawdoctor measure the sawblade he tries to get an opinion over where the lumps are and how much tension he needs to put in to it. However, he can only estimate. His accuracy will totally depend on his skills but will still be too inaccurate for an evaluation of this inspection system. The optimal way of performing this evaluation is to have reference sawblade material. Since reference material are missing the approach has been to connect the information that can be collected from the video inspection system and the topography system.

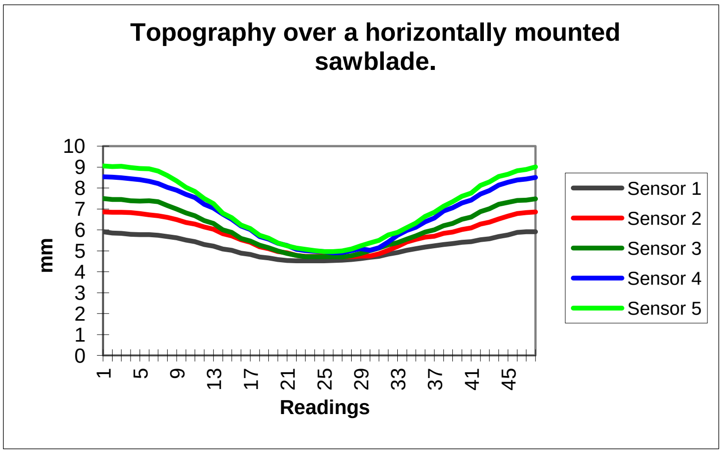


Fig.23. Readings from five sensors and when the blade was mounted horizontally on a hub.

At the start when the blade was mounted horizontally some ”strange buckling” seamed to occur. Readings from the topography looked as in fig.23 and represent data from a sawblade with 24 teeth measured two times a tooth. Was this really the shape of the blade or was it a product of an ill-produced design? Running the blade in the video inspection system could check this. If the runout* from sensor 5 showed similarities to the runout measured by the video inspection system conclusion that fig.24 showed the real topography could be made.

The sawblade was as a result mounted on the vertically attached hub, used for measuring the video inspection system, and recordings from the video microscope over the sawblades runout were performed.

* = how much a sawblade deviates in a cutting perspective.

Tests executed on the same sawblade showed that the video inspection system measured the runout to **1.2 mm** and the runout according to sensor 5 figure.23 was as high as **3.2 mm**. An error was present!

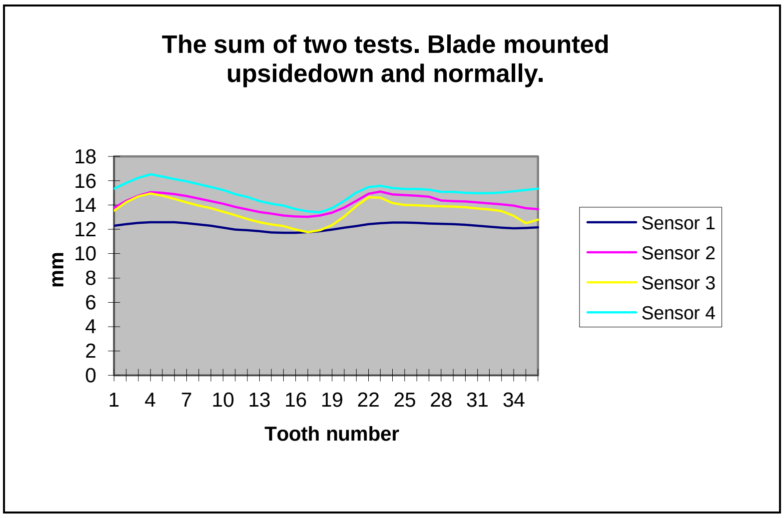


Fig.24. Show the calculated sum of two tests. Blade mounted upside-down and blade mounted normally without changing its position on the hub.

The problems with a too big runout can only depend on two things; how gravity effects the sawblade or misalignment of the hub. To exclude the problems with alignment of the horizontally attached hub, the sawblade was measured in exactly the same position as before but with the blade turned upside-down. If the blade do not experiences effects due to gravity the sum of the two readings would be almost identical and straight line would occur in figure 24. The sum from the new readings where taken in exactly the same positions and the result can be seen in fig.24. A straight line did not occur in figure 24 which led to the conclusion that gravitation plays a vital roll for the results.

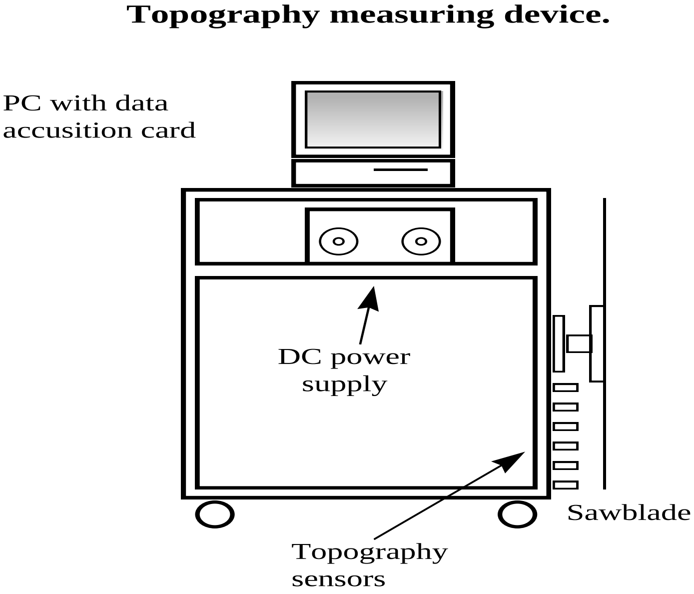


Fig.25. Device when the topography is measured with the blade mounted vertically.

The sawblade was as a result mounted on a vertically attached hub, used for the video inspection system, with the sensors placed differently than before. A difference in the design was due to the fact that when a blade was measured horizontally the bar with all the sensors needed to be removed each time a new blade was measured (see fig.13). This can cause a smaller inaccuracy in the readings and hence not wanted. Another adjustment on the design was made. It can be of interest to watch the sawblades topography while measuring. That can be made by mounting the sensors on the same side of the sawblade centre. The sensors were as a result placed on a bar ”under” the blade see fig 25.

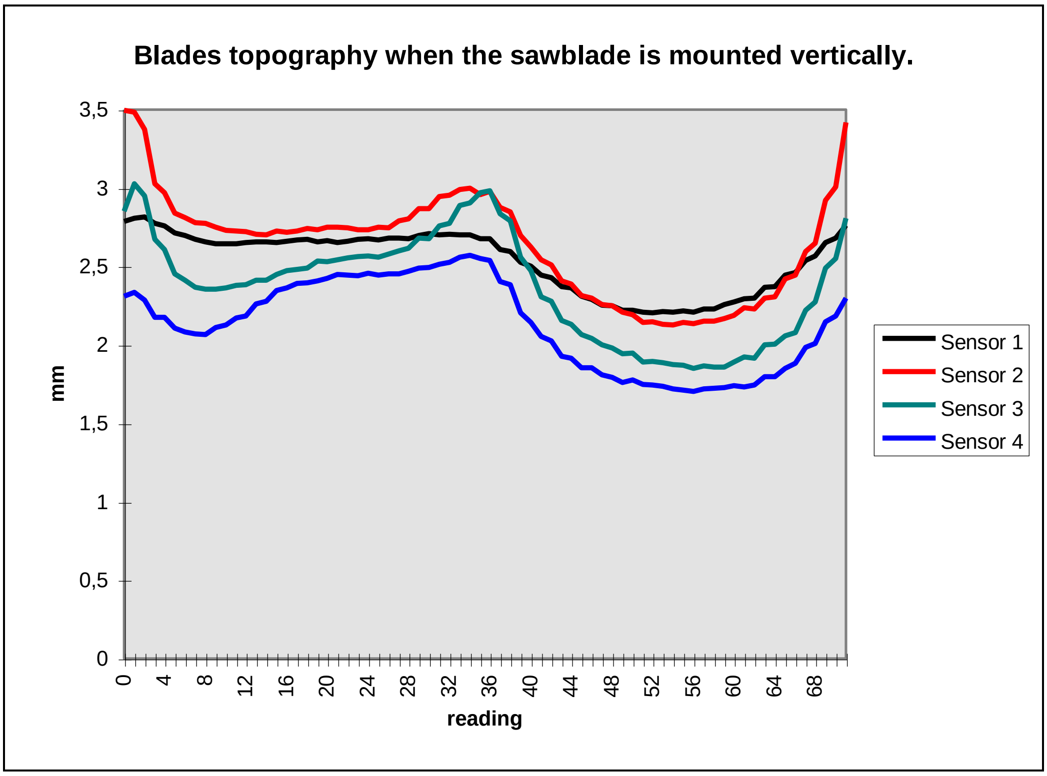


Fig.26. Shows the blades topography while mounted vertically.

When the new design was accomplished and calibrated, new tests were needed. A sawblade was as a result attached to the hub and a recording (two times a tooth) of its topography was made. The result is shown in figure 26. An interesting thing was that the runout, all of a sudden, had decreased to **0.7 mm** which is a level around the runout measured by the video inspection system **1.2 mm**. However, there was still a difference in runout but that can depend on where the runout was measured. With the video inspection system the runout is measured at the teeth but in the case the topography system same runout is measured by sensor 4. The difference with the different measuring points (approximately 6cm) can cause the difference in runout.

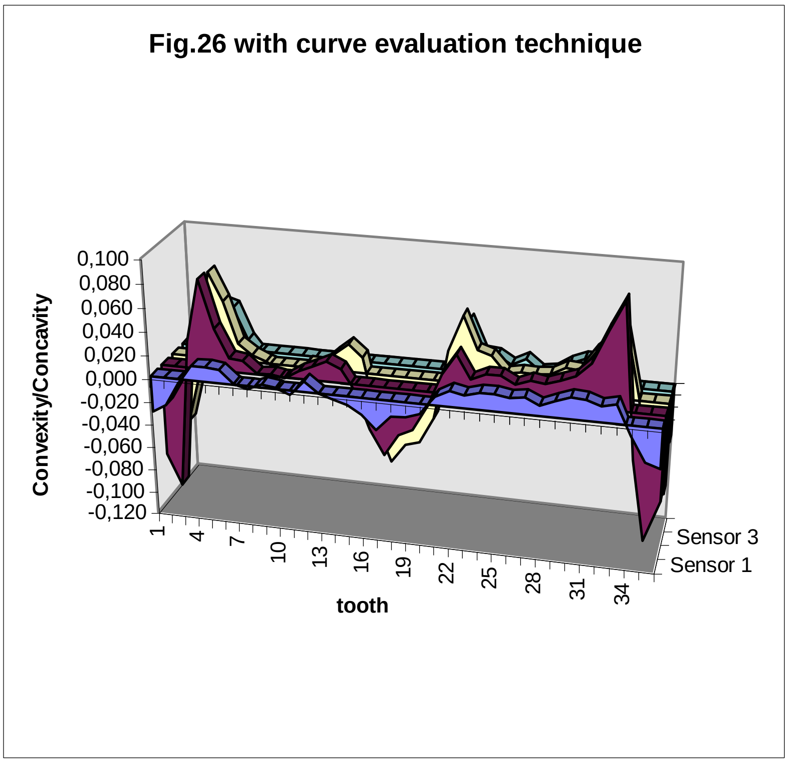


Fig.27. Show the recorded topography in fig.26 with the curve evaluation method.

Connecting the curve evaluation technique (described in section 3.1.2) the topography looks as in figure.27. When the curve cuts x-axis, a lump start or stop and by connecting the information gathered from figure 26 and 27, the lumps and its individual size can be detected. The sawdoctor can then locate the lumps on the sawblade and treat it in a proper way.

At the last test occasion the hubs alignment was about to be tested. Unfortunately damage was caused to the hub putting the sensors in a position where recordings could not be completed. Information from the last test could as a result not be performed.

Development of the topography system can not be seen as a finished system. The questions are still many to answer for instance are five lines sufficient to describe a sawblade's total topography? When is a lump according to the graphs worth taken in consideration?

4.3 Testing sawblades tension.

By measuring the natural frequency of a blade its tension can be determined. The goal of this test was to see if theory of the literature could be seen in our practical results. According to theory and tests performed, desirable results was to find natural frequency peaks around 20 Hz and tendencies to increase the gap to next nearby peaks after tensioning of the sawblade. Since there have not been a uniform answer over how to produce this peaks two different methods were used. Tapping and the use of a pulse generator. Tapping is executed by using a plastic rod on the sawblade’s surface and measures its impact by an accelerometer, (see section 2.3).

Peak drifting (Hz)

	Before tensioning		After tensioning	
Saw ref.	**Peak (2-1)**	**Peak (3-2)**	**Peak (2-1)**	**Peak (3-2)**
Saw12	6.9	7.0	9.7	15.0
Saw23	25.0	19.7	20.8	24.8
Saw212	7.5	9.9	12.7	11.8

Fig.28. The distance in Hz between nearby peaks produced by tapping the blade.

Five tests were executed on three different sawblades with a diameter of 690mm, 36 teeth and #3 sized splined eye. The test was made on new sawblades before and after tensioning. The average of these tests was calculated and analysed in figure 28. The result in figure 28 support the theory that there was a peak drifts when the blade experiences higher tension. The difference between peak 3 and peak 2 (peak (3-2) in tab.2) on a tensioned blade had increased with an average of **8.3 Hz** in comparison to a non-tensioned blade. Unfortunately, the uniformity of the blades peaks after tensioning was harder to find.

After tensioning

	Peak1(Hz)	**Peak2(Hz)**	**Peak3(Hz)**
Saw12	6.7	16.4	31.4
Saw23	10.6	31.4	56.2
Saw212	12.4	25.2	36.9
Newsaw1*	7.8	16.0	24.0

* = New saw with 24 teeth.

Fig.29. Frequency peaks produced by tapping and after tensioning of the blades.

Same amount of tension was rolled into the different sawblades. The lack of uniformity is shown in figure 29. If the uniformity depends on poor tensioning or an inaccuracy in the testing design is difficult to tell.

The second way of producing the frequency was to use a pulse generator. The generator vibrates the blade with a certain frequency and when a strong signal from the accelerometer is recorded (happens in a natural frequency peak) readings of the blade’s natural frequency can be produced. The test was performed on the same sawblades as used for tapping. Regarding the pulse generator following data was collected.

Peak drifting (Hz)

	Before tensioning		After tensioning	
Saw ref.	**Peak (2-1)**	**Peak (3-2)**	**Peak (2-1)**	**Peak (3-2)**
Saw12	14.4	6.0	19.6	30.5
Saw23	6.7	13.8	12.1	11.7
Saw212	7.8	7.0	20.1	13.1

Fig.30. Show the distance in Hz between nearby peaks produced by vibrating the blade with a pulse generator.

The pattern with the drifts in frequency peaks after tensioned was significant even here (see fig.30). The drift was as high as **9.5 Hz** in average between peak 2 and peak 3. Looking at the sawblades uniformity after tensioning a better uniformity presents than when tapping is used.

After tensioning

	Peak1(Hz)	Peak2(Hz)	Peak3(Hz)
Saw12	11.7	31.3	61.8
Saw23	13.1	25.2	36.9
Saw212	11.2	31.3	44.4
Newsaw1*	15.2	19.5	23.0

* = New saw with 24 teeth.

Fig.31. Frequency peaks produced by a frequency generator and after the blades have been re-tensioned.

Excluding newsaw1 in the readings (hard to say how much an extra two teeth affects the frequency) in figure 31, a quite pleasant picture presents. Peak 1 and 2 showed big similarities. It was only peak 3 in Saw 12 readings that seemed to be too high.

It is no question so far, that the pulse generator is a much better alternative than using a plastic rod for tapping. However, a problem occurred while using the pulse generator. The generated peak signals were much weaker than when tapping was used. This was not expected because of the fact that it was the pulse that showed the strongest signal in laboratory environment.

Tuned frequency 22 Hz

Peak	Freq. (Hz)	Stdev (Hz)	Signal(dB)
1	8,6	0,3	-0,3
2	16,7	1,9	-17,5
3	22,8	3,5	-15,8

Fig.32. Accelerometer readings with an input signal of **22 Hz** to pulse generator.

Tuned frequency 27 Hz

Peak	Freq. (Hz)	Stdev (Hz)	Signal(dB)
1	8,6	0,4	-1,6
2	19,0	1,8	-15,0
3	26,9	3,3	-10,7

Fig.33. Accelerometer readings with an input signal of **27 Hz** to pulse generator.

The pulse generator only generates one signal with a certain frequency and when a natural frequency peak of the sawblade have the same frequency as the pulse generator, a strong signal is achieved and recordings can be made. However, since a blade experience more than one natural frequency peaks wrong signal can be tuned into the blade. To answer the question over what to expect when different frequency peaks is tuned an extra test was added. The test was executed by tuning in two natural frequency peaks, (see section 2.4 natural frequency) 22 and 27 Hz five times on each sawblade. The average natural frequency peaks, strength (dB) and how much each peaks deviated between the tests were determined. The data is presented in appendix B and the results can be seen in figure 32 and 33. The result showed that when a higher frequency was tuned the sawblades stiffness seamed to increase. Peak 2 drifted with

2.3 Hz and peak 3 drifted with **4.1 Hz.** This means that right frequency must be tuned to get the correct answer over the blades natural frequency,

The area around the different tuned peaks was also a source of error. The strongest signal has in a number of tests been a big problem to find. In some of the tests has it taken more than 2 min or been impossible to find the right input signal. If mistakes are made different readings will occur that will mislead the operator. The method with using the pulse generator most therefore be improved before it can be used in production.

The two methods, tapping or using a pulse generator has with existing design not achieved the accuracy that a system for the production demands. The next step will be to prove a new pulse generator that sends a random number of pulses with different frequencies into the blade (pink noise). Problems with tuning in the frequency and what frequency to choose will be excluded.

Test according to software PICO ADC-12 was performed. PICO ADC-12 works like an oscilloscope but with less sensitivity and cost much less. By using the PICO ADC-12 in the same way as the oscilloscope with a Main TimeBase (MTB) of 200ms and as a spectroscope (FFT) recording could be performed. When tapping was executed god accuracy in comparison to the oscilloscope was attained. All natural frequency peaks could be detected with an accuracy of ±**0.2 Hz**. The sensitivity when it came to tuning in the right frequency for the pulse generator showed not to be as successful. Optimal signal could never be tuned. The result was that the PICO ADC-12 could bee used if tapping is the method. Since the question over what method use not have been answered PICO ADC-12 will be put aside until an accurate method has been invented.

4.3.1 Self weight test

The test was executed on brand new sawblades with a diameter of 590mm, at a sawblade manufacturer with name ***Checkmate***. To eliminate effects from lumps only new blades where tested.

		Light gap (mm)		
Saw description	**Rim drop(mm)**	**Rep. 1**	**Rep. 2**	**Rep.3**
Saw 1	2,22	-0,59	-0,17	-0,42
Saw 2	2,73	-1,22	-0,2	-1,02
Saw 3	2,82	-0,13	0,28	-0,41
Saw 4	2,14	-2,05	-1,49	-0,56
Saw 5	1,82	-1,1	-0,74	-0,36

Fig.34. Result from test with the light gap method.

The five tests were executed in the same way. Five different sawblades with zero pre-tensioning were used and a bending force was applied to the rim of the sawblade (see fig.13). To make sure that the bending force was exactly the same through out the test the rim drop was measured. Three repetitions were made on the same position and the light gap (see fig.16-17) was measured each time. The result can be seen in figure 34. For some reason, the difference between the repetitions was quite high. Saw 4 experience a difference of **1.49mm** in light gap. The individual difference was also high. By comparing Saw 3 and Saw 4 in repetition 1 gives a difference of **1.92mm**. The result in figure 34 showed such an inconsistency that the self weight test was as a result excluded.

4.4 Testing a statistical method for measuring the blades individual performance.

The test was performed at a sawmill, ***Pan Pacific*** in Naipier. The goal of the test was to determine whether a single sawblade's performance could be determined by measuring the boards and cants in a certain way (see section 3.4). If the individual performance of a sawblade can be determined evidence that support or suppress the readings made by the circular saw inspection system could be collected.

The boards and cants were measured with a slide-calliper in 23 points along the length and on the top as well as the bottom (see fig. 22). The data from the test can be find in appendix C.

Variance stdev(mm)
Top

	Board 1	Board 2	Board 3	Cant
Test 1	0.66	0.72	1.10	1.14
Test 2	0.36	1.38	0.51	1.50
Test 3	0.37	2.16	0.63	0.61
Test 4	0.49	0.61	0.54	0.42
Test 5	0.58	0.96		0.89
Test 6	0.59	0.67		0.20
Test 7	0.63	0.60	0.71	0.16

Fig.35. Variance on each board and cant measured at the top.

Bottom

	Board 1	Board 2	Board 3	Cant
Test 1	0.44	0.46	0.19	0.40
Test 2	0.17	0.66	0.13	0.65
Test 3	0.16	0.08	0.36	0.28
Test 4	0.25	0.16	0.94	1.03
Test 5	0.25	0.45		0.26
Test 6	0.07	0.66		0.75
Test 7	0.19	0.17	0.33	0.33

Fig.36. Variance on each board and cant measured at the bottom.

The thickness deviation was calculated according to equation 2 page 21. The results can be seen in figure 35 and 36. In test 5 and 6, only two boards were produced.

By using the created statistical method (see section 3.4) and by putting in the calculated data, fig.35 and 36, following table below of the individual sawblades performance can be presented.

	Top stdev (mm)			Bottom stdev (mm)		
	saw 0	**saw 1**	**saw 2**	**saw 0**	**saw 1**	**saw 2**
Test 5	0.32	0.48	0.83	Neg.	0.32	0.32
Test 6	Neg.	0.61	0.26	0.25	Neg.	0.70

Fig.37. Calculated variance on each sawblade.

However, the statistical method created problems in a number of ways. One problem was the fact that for an even number of sawblades equation 3 page 21 showed singularity, which means that there can be zero or infinite numbers of solutions to equations3. This result was something that was a little bit unexpected. The results from even numbers of saws, test 1-4 and test 7 in figure 35 and 36, could therefore as a result not be presented.

Looking at the few results being produced another interesting phenomena occurs. Some of the calculated variances showed negative values (see fig.37). A negative number on a variance is ofcourse impossible to achieve, but can still gives certain information of the sawblades real variance. It is likely that a sawblade, which shows negative variance, in real shows variances close to, zero. The calculated variances can therefore be an individual measurement to which blade that is considered best and which is considered worst on that particular set of saws.

If this can be of any help in our case is difficult to say. In any case, more test is needed before any certain evaluation over the statistical method can be carried out.

4.5 Technical data

Saw measuring device.

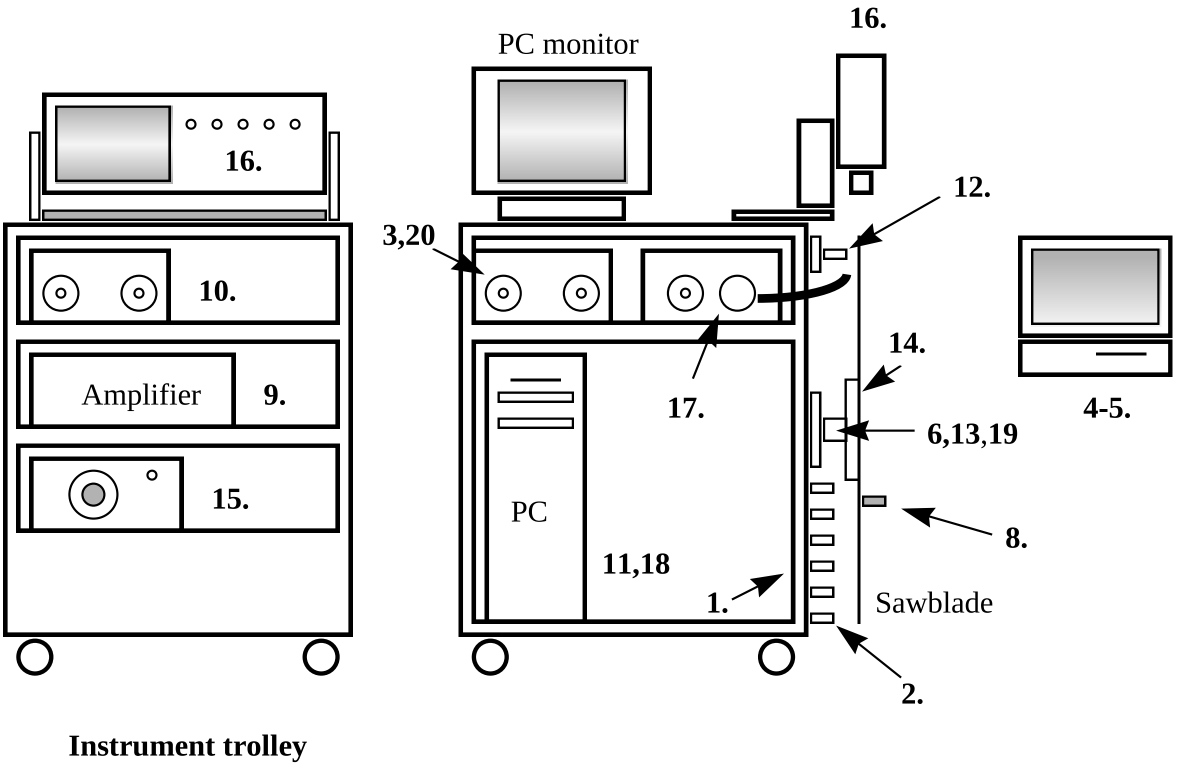


Fig.38. Circular saw inspection system after five months research.

The device after five months research looks as in figure 38 and each part are described with names on following page.

Topography system:

1. Five analog sensors Balluff model BAW 018-PF-1-K with a range of measure of 1.25-8 mm and an accuracy of =< .02 mm at constant temp. A reaction time of 40ms.10-30V supply voltage.
2. One inductive switch sensor Balluff model BES 516-123-B0-C. Repeat accuracy =< 5 %. 10-30 supply voltage.
3. Regulated DC power supply. Wonix model YW APS305.
4. PC+ data acquisition card.
5. Personal computer with software LabVIEW.
6. Suitable stand with a number 3 spline and hub.

Tension system:

7. Accelerometer Sensotec model PEL 63509.
8. Charge amplifier Sensotec model for accelerometer output 5V.
9. Regulated DC power supply. Wonix model YW APS305.
10. Personal computer and data logging software PICO ADC-12
11. 24 V electromagnetic pulse generator with a belonging 2N3772 power transistor.
12. Inspection stand with cast iron central support hub mounted on a suitable bearing spindle and stand with a #3 spline hub.
13. Several of rubber and metal washers.
14. Phase-lock frequency generator. Wawetek 5MHz model 186.
15. Oscilloscope.

Video inspection system:

16. JVC video microscope model TKS240E
17. Optical fibre source Intralux model 5000-1.
18. Personal computer with Video Trace image processing software.
19. Suitable stand with a number 3 splined hub.
20. Regulated DC power supply. Wonix model YW APS305.

5. Discussion

Measuring tension

When a homogeneous pulse is used for vibrating the sawblade it is very important to tune in the right node frequency. Sometimes these frequencies can be very close to each other. If incorrect nodal frequency is tuned, a big difference in the measured natural frequencies will take place. One way to avoid such an error would be to produce a random frequency pulse (pink noise) for vibrating the blade. The PICO ADC-12 (see section 3.2) would then be useful and sufficient for measuring the different nodal peaks.

Measuring topography

Concerning the topography, a source of mistake will always be the rubber washers. When a blade is placed on the hub the washers do not experience same pressure due to difference in forces towards them. The rubber washers can be unequally squeezed and the alignment of the blade will be jeopardised. The runout will be bigger and an unwanted sinus curve will be added to the displayed topography. If a clamp is mounted to the centre of the sawblades and the washers are taken away, the runout and the topography could be measured with a higher degree of accuracy. If tension is measured on a clamped blade the natural frequency would be much higher. The nodes and modes would still be there but to a higher frequency. The correlation to a perfect blade could still be possible to make and to gain of better readings.

When the blade was mounted horizontally, a test was executed trying to determine whether the error depended on the hub or gravity. To make the conclusion as described in the report can be a quite risky because a perfectly align hub must in any case be made before any kind of testing can be executed.

Video inspection system

The design that is produced does not have the ability to measure the gullet and top clearance angle (see section 2.1-2.4). It is easily accomplished by putting a joist on the stand of the video microscope. By leaning the stand in a 90-degree angle over the sawblade, the gullet and top clearance angle can be measured.

This study tries to make conclusions without reference material (sawblades). It is made because of lack of a device that can measure a sawblade’s real topography. If there would be reference material available errors would be much easier to determine to benefit for a faster development of the whole project.

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Appendix A: Test concerning accuracy of Video Inspection system.

Calibration 84,8 pixels/mm

Side clearance angle(deg.)

Tooth no.	Left angle	Right angle	Tip width	Tip width (mm)
1	88,4	86,9	282	3,33
5		87	145	1,71
6	86,7	88,3	315	3,71
7	88,6	86,6	324	3,82
9	88,9		262	3,09
10	87,1	86,5	329	3,88
11	87,1	86,1	334	3,94
12	87,4	86,4	333	3,93
16	87,5		275	3,24
18	87,8	87,3	277	3,27
22	87,1	84,3	296	3,49
23	87,1	84,5	313	3,69

Calibration 105,4 pixels/mm

Side clearance angle(deg.)

Tooth no.	Left angle	Right angle	Tip width	Tip width (mm)
1	87,4	86,8	347	3,29
5		87,1	188	1,78
6	86,6	86,9	388	3,68
7	88	86,6	395	3,75
9	88		337	3,20
10	87,5	85,8	408	3,87
11	86,6	88,5	478	4,54
12	87,1	87,6	413	3,92
16	87,5		344	3,26
18	87	86,2	339	3,22
22	87,1	85,8	365	3,46
23	87,5	84,8	383	3,63

Calibration 83,6 pixels/mm

Side clearance angle(deg.)

Tooth no.	Left angle	Right angle	Tip width	Tip width (mm)
1	87,5			
5		86,4		
6	85,7	87,1	330	3,95
7		86		
10	86,1	86,3	326	3,90
11	86,4	87,2	345	4,13
12	86,8	87,4	329	3,94
16	86,3			
22	86,2			
23	87,1	84,8	314	3,76

Calibration 103,6 pixels/mm

	Side clearance angle(deg.)			
Tooth no.	Left angle	Right angle	Tip width	Tip width (mm)
1	88,9	87,5	341	3,29
5		86,4	176	1,70
6	86,6	88,6	382	3,69
7	88,5	85,8	394	3,80
9	87,7		321	3,10
10	87,7	85,1	400	3,86
11	86,8	87,4	409	3,95
12	87,1	86	403	3,89
16	86,9		338	3,26
18	86,5	86,9	325	3,14
22	87	84,5	350	3,38
23	87,2	85,1	380	3,67

Calibration 108 pixels/mm

	Side clearance angle(deg.)			
Tooth no.	Left angle	Right angle	Tip width	Tip width (mm)
1	87,3	87,8	351	3,25
5		87,6	179	1,66
6	86,6	88,6	404	3,74
7	87,9	85,3	406	3,76
9	88		338	3,13
10	87,4	86,5	422	3,91
11	85,8	86,7	474	4,39
12	87,6	86	393	3,64
16	87,1		352	3,26
18	87,8	87,7	324	3,00
22	86,8	85,9	377	3,49
23	87,2	85	390	3,61

☐ Not damage!

Conclusion concerning accuracy of the Video Inspection system.

	Clearance angle **Left angle**	**Right angle**	**Tip width**
Tooth no.	**Stdev(deg.)**	**Stdev(deg.)**	**Stdev(mm)**
1	0,71		
5		0,51	
6	0,42	0,81	
7		0,55	
10	0,63	0,60	0,02
11	0,49	0,89	0,27
12	0,31	0,90	0,13
16	0,50		
22	0,38		
23	0,16	0,23	0,06

Precision in average stdev

Clearance angle (deg.)	**Tip width (mm)**
0,59	**0,14**

Appendix B: Readings with different input signals to the pulse generator.

Tuned frequency 22 Hz

	Peak 1(Hz)	**Signal (dB)**	**Peak 2 (Hz)**	**Signal (dB)**	**Peak 3 (Hz)**	**Signal (dB)**
Test 1	8,01	-2,3	11,3	-12,5	21,5	0
Test 2	8,4	0	16,3	-17	21,7	-15,9
Test 3	8,5	0	16,8	-21,5	21,7	-27,5
Test 4	8,59	0	16,9	-26	21,7	-20,4
Test 6	8,74	0	17,2	-13,6	21,8	-21,5
Test 7	8,79	0	17,6	-21,5	21,8	-17
Test 8	8,84	0	17,8	-20,4	21,9	-14,7
Test 9	9,03	0	17,8	-12,5	32,8	-4,6

Tuned frequency 27 Hz

	Peak 1(Hz)	**Signal (dB)**	**Peak 2 (Hz)**	**Signal (dB)**	**Peak 3 (Hz)**	**Signal (dB)**
Test 1	8,2	0	16,4	-28,3	21,2	-13,6
Test 2	8,4	0	17,8	-6,8	27	0
Test 3	8,5	0	19,7	-2,3	28,3	-2,3
Test 4	8,59	0	20,5	-19,3	28,9	-20,4
Test 5	9,28	-8	20,5	-18,1	28,9	-17

Conclusion.

Tuned frequency 22 Hz

Peak	**Freq. (Hz)**	**Stdev (Hz)**	**Signal(dB)**
1	8,6	0,3	-0,3
2	16,7	1,9	-17,5
3	22,8	3,5	-15,8

Tuned frequency 27 Hz

Peak	**Freq. (Hz)**	**Stdev (Hz)**	**Signal(dB)**
1	8,6	0,4	-1,6
2	19,0	1,8	-15,0
3	26,9	3,3	-10,7

Appendix C: *Test statistical method.*

Other info. **Before changing blades!**

Cant(mm)

Reading	Top	Bottom
1	89,72	88,68
2	90,62	89,12
3	92,03	90,02
4	93,18	90,01
5	94,19	90,15
6	93,95	90,38
7	93,79	90,09
8	93,33	89,83
9	93,17	89,97
10	93,03	89,85
11	92,95	89,68
12	92,91	89,85
13	93,52	90,3
14	93,79	90,12
15	93,87	90,09
16	93,98	90,16
17	93,99	90,31
18	93,83	90,16
19	93,35	90,07
20	92,42	89,6
21	92,4	89,57
22	91,68	89,41
23	91,74	89,74

Blade ref. **Saw12 and 23.**
Name **Test 1**
Boards **Top(mm)**

Reading	Board 1	Board 2	Board 3
1	27,64	29,01	25,29
2	27,66	28,58	26,28
3	27,58	28,1	28,21
4	27,64	28,21	29,38
5	27,62	28,66	29,55
6	27,9	28,93	29,5
7	28,6	28,88	29,15
8	27,95	28,93	28,84
9	27,82	29,16	28,51
10	27,68	29,57	28,08
11	27,68	29,75	27,74
12	27,47	29,92	27,68
13	27,33	29,63	28,67
14	27,26	29,76	28,87
15	27,36	29,71	28,91
16	27,59	29,82	28,84
17	27,92	29,62	28,87
18	28,1	29,38	28,67
19	28,21	29,2	28,54
20	28,56	28,82	27,61
21	28,99	28,45	26,91
22	29,34	27,84	26,61
23	29,84	27,12	27,39

Bottom(mm)

Reading	Board 1	Board 2	Board 3
1	25,47	27,86	27,96
2	25,74	27,99	28,19
3	26,54	28,02	27,73
4	27,06	27,95	27,7
5	27,05	29,93	27,92
6	27	27,9	27,97
7	26,77	27,93	28,19
8	26,66	28,03	28,13
9	26,67	28,01	28,3
10	26,37	28,01	28,19
11	26,07	28,15	28,22
12	26,4	28,06	28,18
13	26,58	28,17	28,27
14	26,52	28,23	28,29
15	26,51	28,16	28,28
16	26,59	28,26	28,26
17	26,67	28,25	28,22
18	26,48	28,44	28,23
19	26,19	28,56	28,21
20	25,9	28,58	28,27
21	25,76	28,64	28,21
22	25,81	28,75	28,16
23	26,08	28,83	27,71

Time 1600-1615
Other info. **After changing blades!**

Blade ref. **Saw212 and 223.**
Name **Test 2**

Cant(mm)

Reading	Top	Bottom
1	95,06	90,72
2	95,43	91,06
3	95,55	92,82
4	95,45	91,32
5	95,34	90,99
6	95,53	91
7	95,33	91,05
8	94,8	91,6
9	94,17	91,08
10	93,43	90,69
11	92,7	90,28
12	92,53	90,15
13	92,4	90,08
14	92,73	90,27
15	93,07	90,36
16	92,88	90,41
17	92,67	90,24
18	92,31	90,32
19	91,9	90,23
20	92,56	90,24
21	92,17	90,41
22	91,86	90,15
23	91,52	90,13
24	90,83	89,86

Boards **Top(mm)**

Reading	Board 1	Board 2	Board 3
1	29,15	31,82	27,44
2	29,6	32,04	27,03
3	29,42	32,66	26,76
4	29,01	33,02	26,31
5	28,77	32,92	26,54
6	28,75	32,35	26,98
7	29	31,9	27,44
8	29,02	31,51	27,46
9	29,11	30,58	27,39
10	29,3	30,05	27,2
11	29,11	29,77	26,82
12	28,77	29,78	26,98
13	28,71	29,84	27
14	28,89	29,97	26,84
15	28,96	29,82	27,29
16	29,16	29,72	27,28
17	28,96	29,8	26,44
18	28,79	30,62	26,21
19	28,51	30,19	26,37
20	28,58	30,18	27,32
21	28,35	29,37	27,71
22	28,53	28,43	28,12
23	28	28,16	27,9

Bottom(mm)

Reading	Board 1	Board 2	Board 3
1	27,29	28,84	28,05
2	27,49	29,03	28,16
3	27,4	29,88	27,97
4	27,34	29,29	27,9
5	27,24	29,12	27,8
6	27,4	29,02	27,95
7	27,7	28,92	28,01
8	27,76	28,67	27,98
9	27,67	28,37	28,03
10	27,77	28,04	28,05
11	27,68	27,86	28,1
12	27,51	27,8	27,96
13	27,51	27,78	27,79
14	27,71	27,96	27,95
15	27,57	28,11	28
16	27,67	27,83	27,81
17	27,66	27,74	27,62
18	27,83	27,93	27,83
19	27,76	27,95	27,8
20	27,73	27,72	28,05
21	27,55	27,84	28,11
22	27,68	27,54	28,1
23	27,5	27,51	28,07

Date 990311
Time 0837-0900
Other info. **Same blade!**

Name **Test 3**
Blade ref. **Saw212 and 223.**

Cant(mm)

Reading	Top	Bottom
1	91,65	90,62
2	91,71	91,07
3	91,38	90,93
4	91,19	90,77
5	91,02	90,76
6	91,61	90,93
7	92,03	91,04
8	92,38	91,03
9	92,59	91,25
10	92,14	91,27
11	91,21	90,83
12	91,26	90,75
13	91,73	90,64
14	92,22	90,85
15	92,84	91,25
16	92,81	91,44
17	92,84	91,49
18	92,09	91,47
19	92,05	91,22
20	91,47	91,17
21	91,46	91,09
22	91,04	90,83
23	90,83	90,45

Boards Top(mm)

Reading	Board 1	Board 2	Board 3
1	29,21	27,37	28,23
2	29,02	37,42	28,54
3	28,62	27,09	28,76
4	28,37	27,26	28,81
5	28,37	27,03	28,69
6	28,67	27,11	28,78
7	28,82	27,31	28,91
8	28,9	27,31	29,24
9	28,75	27,59	29,32
10	28,51	27,73	28,81
11	28,05	27,62	28,58
12	28,18	27,65	28,63
13	28,35	27,7	28,83
14	28,7	27,51	29,1
15	28,82	27,31	29,69
16	28,91	26,95	29,97
17	28,89	26,74	29,99
18	28,81	26,72	29,87
19	29,1	26,7	29,47
20	29,05	27	28,48
21	29,37	27,18	28,12
22	29,3	26,88	27,7
23	29,41	26,63	27,91

Bottom(mm)

Reading	Board 1	Board 2	Board 3
1	27,59	28,05	28,12
2	27,79	28,08	28,41
3	27,84	28,07	28,29
4	27,8	28,02	28,16
5	27,77	28,05	28,23
6	27,96	28,04	28,23
7	27,75	28,07	28,27
8	27,66	28,07	28,6
9	27,69	28,14	28,61
10	27,65	28,16	28,65
11	27,77	28,23	28,43
12	27,8	28,04	28,06
13	27,88	28,11	27,97
14	27,9	28,14	28,17
15	27,93	28,04	28,42
16	27,83	28,06	28,8
17	27,67	28,03	29,15
18	27,77	27,97	28,89
19	27,9	27,81	28,77
20	28,08	27,96	28,47
21	28,11	27,96	28,09
22	28,25	28,06	27,88
23	28,02	28,09	27,54

Date 990311
Name **Test 4**
Time 1100-1130
Blade ref. **Saw212 and 223.**
Other info. **After this cut some adjustments was made!**

Cant(mm)

Reading	Top	Bottom
1	92,64	91,73
2	92,74	91,26
3	92,46	91,2
4	93,36	90,68
5	92,44	90,8
6	92,02	90,37
7	91,93	90,01
8	91,86	89,3
9	91,82	89,32
10	91,81	89,08
11	91,74	88,67
12	91,66	88,6
13	91,92	88,5
14	91,71	88,6
15	91,7	88,3
16	91,76	88,74
17	91,8	88,75
18	91,9	89,07
19	91,95	89,2
20	91,75	89,03
21	91,67	88,44
22	91,78	88,67
23	92,06	88,46
24	91,73	89,16

Boards **Top(mm)**

Reading	Board 1	Board 2	Board 3
1	28,72	27,25	29,35
2	28,99	26,95	29,45
3	28,5	26,88	29,93
4	28,57	27,05	29,59
5	28,67	27,4	29,07
6	28,65	27,57	28,56
7	28,87	27,36	28,52
8	28,92	27,24	28,49
9	28,84	27,43	28,31
10	28,94	27,37	28,38
11	28,88	27,31	28,31
12	28,81	27,22	28,28
13	29,19	26,99	28,45
14	29,2	26,62	28,65
15	29,33	26,23	28,99
16	29,32	25,83	29,53
17	29,38	25,75	29,54
18	29,51	25,95	29,58
19	29,81	26,22	29,57
20	29,71	26,02	28,99
21	29,69	26,29	28,64
22	29,87	26,47	28,41
23	30,42	25,82	28,35

Bottom (mm)

Reading	Board 1	Board 2	Board 3
1	27,26	27,89	28,64
2	27,98	27,98	28,18
3	28	27,74	28,01
4	28,02	27,8	27,83
5	28,09	27,95	27,73
6	27,83	28,07	27,35
7	27,62	27,96	26,97
8	27,6	27,9	26,73
9	27,55	27,94	26,67
10	27,67	27,93	26,48
11	27,67	27,91	26,25
12	27,8	28	25,79
13	27,9	27,84	25,82
14	27,9	27,78	25,69
15	28,07	27,65	25,5
16	28,17	27,62	25,58
17	28,15	27,6	25,94
18	28,21	27,5	26,18
19	28,18	27,57	26,43
20	28,15	27,58	26,19
21	28,12	27,82	25,78
22	27,93	27,69	25,73
23	27,87	27,72	25,84

Date	990311	Name	**Test 5**
Time	1430-1450	Blade ref.	**Saw312**
Other info.	**Changed one blade Board 12!**		

Cant(mm)

Reading	Top	Bottom
1	68,4	67,66
2	68,76	67,71
3	69,2	67,83
4	69,16	68,3
5	70,22	68,46
6	70,96	68,44
7	70,67	68,51
8	70,66	68,19
9	70,72	68,49
10	71,27	68,62
11	71,42	68,49
12	71,26	68,41
13	70,99	68,19
14	71	68,19
15	71,12	68,2
16	71,16	68,28
17	70,91	68,32
18	70,92	68,35
19	71,02	68,53
20	71,31	68,35
21	71,25	68,42
22	71,46	68,38
23	71,31	68,54

Boards **Top(mm)**

Reading	Board 1	Board 2
1	33,69	31,21
2	33,59	31,63
3	33,12	32,42
4	33,01	33,1
5	33,11	33,68
6	33,83	33,61
7	34,3	33,16
8	34,66	32,8
9	34,8	32,62
10	34,98	32,78
11	34,86	33,09
12	34,54	33,43
13	34,46	33,11
14	34,43	33,12
15	34,33	33,2
16	34,39	33,39
17	34,12	33,33
18	33,99	30,3
19	33,8	33,63
20	33,76	33,95
21	33,6	34,11
22	33,68	34,32
23	33,47	34,33

Bottom(mm)

Reading	Board 1	Board 2
1	33,1	31,09
2	32,95	31,32
3	32,96	31,36
4	32,86	31,9
5	32,84	32,38
6	32,33	32,8
7	32,41	32,83
8	32,4	32,43
9	32,81	32,67
10	33	32,35
11	32,96	32,2
12	33,01	32,32
13	32,97	31,92
14	33,21	31,62
15	33,08	31,7
16	33,08	31,73
17	33,29	31,76
18	33,07	31,8
19	33,05	31,96
20	33,15	31,85
21	33,02	31,89
22	33,01	31,96
23	33,01	32,03

Date	990311	Name	**Test 6**
Time	1630-1655	Blade ref.	**Saw 312**
Other info.			

Cant(mm)

Reading	Top	Bottom
1	68,46	71,01
2	68,59	71,41
3	68,62	71,6
4	68,68	71,86
5	68,88	71,93
6	68,76	71,6
7	68,77	71,63
8	68,6	71,57
9	68,57	70,96
10	68,47	71,24
11	68,67	71,31
12	68,67	71,17
13	68,63	70,99
14	68,52	71,94
15	68,38	70,92
16	68,31	71,02
17	68,49	71,16
18	68,71	71,14
19	68,73	70,79
20	68,13	70,25
21	68,28	69,96
22	68,27	69,45
23	68,2	69,02

Boards **Top(mm)**

Reading	Board 1	Board 2
1	34,17	31,04
2	33,86	31,21
3	33,1	32,13
4	32,7	32,73
5	31,91	33,22
6	32,12	33,17
7	32,32	32,94
8	32,92	32,41
9	33	32,13
10	32,96	32,25
11	33,06	32,05
12	33,22	31,88
13	33,01	32,11
14	32,82	32,09
15	33,12	31,79
16	33,64	31,26
17	33,82	31,2
18	33,87	31,4
19	34,02	31,29
20	33,58	31,28
21	33,46	31,32
22	33,45	31,34
23	33,33	31,34

Bottom(mm)

Reading	Board 1	Board 2
1	33,4	34,17
2	33,42	34,51
3	33,55	34,64
4	33,54	34,91
5	33,45	34,97
6	33,43	34,68
7	33,35	34,64
8	33,48	34,62
9	33,42	34,21
10	33,41	34,29
11	33,37	34,36
12	33,57	34,26
13	33,47	34,15
14	33,37	34,12
15	33,44	34,1
16	33,5	34,24
17	33,47	34,18
18	33,48	33,85
19	33,53	33,4
20	33,46	33,23
21	33,32	32,88
22	33,38	32,22
23	33,29	33,48

Date 990312
Time 0830-0845
Other info. **Before changing blades!**

Name **Test 7**
Blade ref. **Saw 412 and 423**

Cant(mm)

Reading	Top(mm)	Bottom
1	89,79	91,19
2	89,89	91,12
3	90,06	91,29
4	90,15	91,2
5	90,04	91,53
6	90,06	91,57
7	90,08	91,66
8	90,1	91,41
9	90,19	91,41
10	90,24	91,55
11	90,04	91,37
12	89,96	91,32
13	89,92	91,26
14	89,89	91,46
15	89,83	91,52
16	90,02	91,41
17	90,02	91,54
18	90,31	91,11
19	89,92	91,73
20	90,16	91,72
21	89,81	91,43
22	89,68	91,06
23	89,84	90,08

Boards **Top(mm)**

Reading	Board 1	Board 2	Board 3
1	27,55	26,63	27,99
2	27,67	26,94	27,87
3	27,08	27,33	28,18
4	26,73	27,77	28,04
5	26,26	28,35	27,88
6	25,98	28,45	28,26
7	25,89	28,23	28,45
8	26,33	27,64	28,79
9	26,33	27,24	28,95
10	27,13	26,67	29,2
11	27,15	27,03	28,49
12	27,47	27,11	27,99
13	27,52	27,31	27,63
14	27,61	27,54	27,63
15	27,54	27,05	27,69
16	27,58	26,98	27,81
17	27,69	26,82	27,95
18	27,86	26,91	27,89
19	27,71	27,27	27,46
20	27,41	28,18	27
21	27,08	28,51	26,64
22	27,51	28,24	26,58
23	28,07	27,72	26,5

Bottom(mm)

Reading	Board 1	Board 2	Board 3
1	28,14	27,63	28,19
2	27,88	27,53	28,49
3	28	27,45	28,39
4	27,92	27,61	28,28
5	27,82	28,18	28,3
6	27,81	28,01	28,45
7	27,79	27,98	28,61
8	27,83	27,86	28,46
9	27,87	27,76	28,42
10	28,14	27,74	28,61
11	28,04	27,82	28,42
12	28,01	27,71	28,22
13	28,2	27,94	27,9
14	28,26	27,81	28,03
15	28,13	27,8	28,24
16	27,98	27,8	28,28
17	28,15	27,83	28,42
18	28,1	27,89	28,72
19	27,84	27,57	28,73
20	27,9	27,73	28,62
21	27,74	27,96	28,37
22	27,65	27,81	27,96
23	27,53	27,76	27,22

Summary Statistical method.

Wedge (mm)

	Board 1	Board 2	Board 3	Cant
Test 1	1,60	0,71	0,06	3,06
Test 2	1,29	2,40	-0,87	2,78
Test 3	0,95	-0,41	0,53	0,80
Test 4	1,26	-1,05	2,33	2,59
Test 5	1,08	1,06		2,36
Test 6	-0,25	-2,20		-2,50
Test 7	-0,76	-0,32	-0,45	-1,35

Variance boards stdev (mm)

	Top				Bottom			
	Board 1	Board 2	Board 3	Cant	Board 1	Board 2	Board 3	Cant
Test 1	0,66	0,72	1,10	1,14	0,44	0,46	0,19	0,40
Test 2	0,36	1,38	0,51	1,50	0,16	0,65	0,13	0,65
Test 3	0,37	2,16	0,63	0,61	0,16	0,08	0,36	0,28
Test 4	0,49	0,61	0,54	0,42	0,25	0,16	0,94	1,03
Test 5	0,58	0,96		0,89	0,25	0,45		0,26
Test 6	0,59	0,67		0,20	0,07	0,66		0,75
Test 7	0,63	0,60	0,71	0,16	0,19	0,17	0,33	0,33

Variance sawblade stdev (mm)

	Top			Bottom		
	saw 0	saw 1	saw 2	saw 0	saw 1	saw 2
Test 5	0,32	0,48	0,83	Negative	0,32	0,32
Test 6	Negative	0,61	0,26	0,25	Negative	0,70