Central Basics of Sonic Tree Tomography

By Frank Rinn • Rinntech, Inc.

INTRODUCTION

Sonic measurements have been used for strength classification of utility poles since the 1960's. Tapping with a hammer on one side of the pole induces a sound wave. A sensor at the other end of the pole detects when the stress wave arrives. The distance between tapping point and detector location is then divided by the measured time of flight, delivering a sonic speed. The higher this speed, the higher the modulus of elasticity, a good measure of wood quality and load carrying capacity. Starting in 1990, this principle was used on standing trees in order to identify internal damages; however this approach was found to be quite limited in exactness and reliability. The principles working well while measuring lengthwise to the fibers do not apply in the same ways when measuring perpendicularly for finding internal damages in cross-sections (Niemz 2001).

In 1999, the first stress-wave tomograph was presented and patented (Rinn 1999) for measuring travel time of sound waves simultaneously between many sending and receiving sensors. Physical principles are still the same but application of the method and interpretation of results need a basic understanding of the functional properties.

A KIND OF VOODOO

In utility poles, the straight distance between the tapping point and the detector approximately equals the real length of the path the stress wave traveled through the wood (longitudinal along with the fibers). Using this method perpendicular to the fibers across a tree trunk, nearly everything gets more complicated. When the hammer taps on a sensor, this electronically switches on the clocks in all other sensors. As soon as the 'sound' arrives at a receiving sensor, the vibrating stress wave stops the clock in this sensor. This way, the 'time of flight' of the fastest part of the sound (=stress) wave is measured. But, the real travel path of this fastest impulse is not known. Only if the wood is intact, the fastest stress waves mostly travel on the straight line between hammer and detecting sensor.

As soon as there is damage somewhere on this straight path between tapping point and receiving sensor, the sound waves have to take a detour. The bigger the damage the longer the detour and thus the higher the measured value ('time of flight'). Because the inspector usually does not know the internal condition, the only chance for calculating a 'sonic speed' is to use the direct distance between tapping point and receiving sensor and dividing it by the time of flight (knowing that the encountered sonic wave in reality probably travelled a longer but unknown path).
Consequently, the stress-wave speed displayed by the sonic device is not the real speed the sound wave traveled, as soon as there are damages between the sensors in the cross section (leading to detours of the waves). The speed values such a sstress wave timer or a sonic tomograph display can thus be called 'apparent' or 'virtual'.

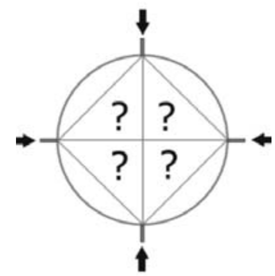
In math, an equation can be solved explicitly for one variable only, when all other variables and parameters are known. Here, in sonic tomography, 2 of 3 variables are not known:

$$\text{(Average) Speed} = \text{Travel path length} / \text{Time of flight}$$
$$v = d / t$$

The real travel speed and the real travel path are not known when tomographing a tree cross-section. Thus, this equation cannot be solved mathematically. The results of sonic tomography, consequently, are a kind of voodoo in the sense that the virtual speed values given (v) are not real. But because they are the only facts that can be measured this way, the tomographic pictures have to be created from virtual values. For solving this difficult situation, the different manufacturers of sonic tomography systems went quite different ways and, consequently, the results for the same cross section may not always be identical.

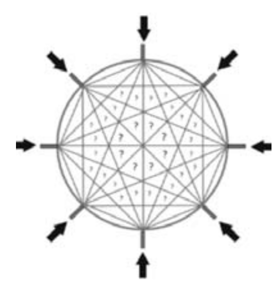
For one type of machine, for example, the internal tomographic reconstruction algorithm is highly sensitive on correct sensor

The number of sensors is critical because the more connection lines that are present between sensor positions, the higher the potential resolution, exactness and reliability of the tomographic result.



The remaining uncertainties and unknown areas are shown here with question marks in different sizes.

Using 2 or even 4 sensors still leaves significant parts of the cross section uninspected. With 8 sensors, such a circular cross section is well analyzed. If there would be a deterioration of critical size in terms of stability, it would surely have been detected somehow with this setup.



However, the more complex a cross-section, the more sensors are required. Currently, for most urban trees, 10 to 16 sensors seem to be a good compromise between costs and results.

positions. For this machine, a caliper is required. Another sonic tomograph system is quite robust in in this sense and accepts imprecision in sensor positioning by several inches, because the algorithm compensates for such mistakes automatically. Using this tomograph, the major results do not differ significantly between exactly measured sensor positions and estimated ones. However, this is only one of several significant differences between the various sonic tomography devices from different manufacturers on the market.

THE NUMBER OF SENSORS IS CRITICAL

The original 2-point measurement was good lengthwise to the pole or beam in order to determine modulus of elasticity. But, this approach was not designed for and was shown to be not suitable for assessing the internal situation of a cross-section. Consequently, before tomographic systems had been available, stress-wave timers were often used by tapping on many positions around the circumference of a tree while subsequently changing the position of the receiving sensor and then repeating the tapping. This took quite a long time, was expensive, and created a mess of data, mostly noted by hand. Still, even well trained experts could only guess what was inside.

However, the first motivation for developing a sonic tomograph for tree inspection was born by the frustration about the broad misuse of the resistance drilling method I developed in the 1980's (Rinn 1988). This misuse of 'my' method in combination with broadly misinterpreted failure criteria led to countless erroneous evaluations of tree stability, with the result of many unnecessary crown toppings and tree fellings. As a consequence, many tree experts and even scientists stated: "Drilling kills trees."

The following reasons make clear where this criticism came from:

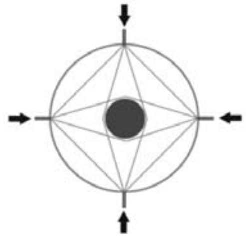
- The urban trees that have to be inspected in terms of safety are commonly mature, their trunk cross-section is often not circular and the decay is often not located in the center.
- The load carrying capacity of a cross section is highly dependent on its size and shape.
- The weakening of the load carrying capacity by internal decay depends more on location of the decay than on the size of the damages.

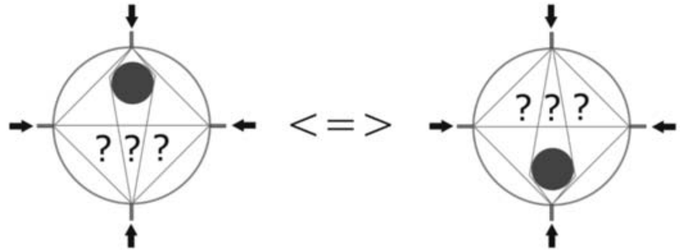
Consequently, one drilling cannot really tell what is inside and how to evaluate the safety of the corresponding tree.

In addition,

- shape, trend, and variation of the profile strongly depend on the point and direction of drilling, and
- quality and reliability of the results of a resistance drilling strongly depend on precision of the drilling machine and reproducibility of the obtained profile.

If there is a central rotten zone or void in the cross-section, all connecting lines between opposing sensors are disturbed (bent out) and the stress waves have to take a detour. This leads to correspondingly lower (virtual) sound speed and can thus be identified (in comparison to the speed from the undisturbed / straight lines).





If a decay is not located in the center, with 4 sensors it is mostly impossible to determine location and size of the decay even in simple small circular cross-sections. Thus, more sensors are needed to come to a reliable result.

Yet only the profiles of density-calibratable resistance drills have been shown to be reliably interpretable (Rinn 2012, 1013). These machine types are commonly equipped with an electronic regulation and recording mechanism, thus more expensive and quite rare on the market.

To solve this sad situation, we started developing a tomographic system in the 1990's. The aim was to provide experts with a device that allows one to determine the cross-sectional size and shape, information about the internal situation and the remaining load carrying capacity. But, using such a device, it has to be taken into account that correct placing of the sensors is as important as having enough sensors for a specific cross-section. If a tree has 4 major buttresses, for example, one sensor should be placed on every root and one in between, so that the positions of the sensors represent the major points determining the geometry of the circumference.

MORE THAN JUST SOME BENEFITS

Even the best diagnostic machine is just an additional tool helping good experts get better in their evaluation. But, a colored tomographic picture can help in many ways: it does not only assist the expert in making a better and more precise evaluation of stability and safety of trees, it is a reliable document and helps explain the findings, evaluations and conclusions to clients, authorities, and to the public (even in a later defense of conclusions).

Tomographic assessments display a special kind of information on the current internal situation but this does not necessarily represent wood condition. Why this is very fortunate shall be explained in a future article. Some tomographic device types determine strength loss due to internal damages – and this shows to be the major advantage of sonic tomography as compared to any other currently established

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method. However, there is no information on decay compartmentalization and expected future compensatory radial increment growth. These aspects currently can only be assessed by density-calibratable, high-resolution resistance drilling. But, for identifying densified compartmentalization zones and tree-ring structures, a high resolution and a clear correlation to wood density is mandatory (which requires a density-calibratable resistance drill with a high correlation coefficient). Thus, proper resistance drilling is a helpful additional tool if the results of sonic tomography show that action is required for achieving sufficient safety or to keep a certain safety level.

In order to evaluate if investments in pruning and/or cabling make sense, the future development of decay and compensatory increment growth has to be estimated. If the drilling profiles show that decay stopped extending and that radial increments are significant, it is much easier recommending the tree owner to invest money and time for (probably expensive) tree care.

However, all this requires a basic understanding not only of the machines and their functional principles but also wood anatomy and tree biomechanics.

Besides managing RINNTECH (manufacturing, selling, and training), he works as an expert inspecting trees and timber structures and gives lectures and training. Since 2001, Frank serves as voluntary Executive Director of ISA Germany and represented his chapter on several board meetings. From 2011 to 2013, he was member of the ISA board of directors 2011-2013. In addition, Frank joined the ISA Tree-Risk Panel of Experts and contributed to the BMP as well as to the corresponding German standard.

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