Wood quality measurement – *son et lumière*

Mike Andrews[1]

Age diminishes faith, but now I have something to believe in. I believe that if a length of cut timber is excited into longitudinal acoustic resonances, its average Modulus of Elasticity can be found from the resonant frequencies and its density. Moreover, this value will equal that obtained from mechanical bending experiments.

People have been making acoustic measurements on wood for more than twenty years, with variable results. Why did it take so long to arrive at this statement, and why has industry suddenly taken acoustic measurements seriously?

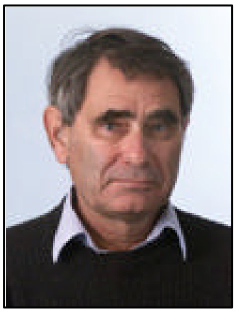
I think the answer lies in a better understanding of the measurement and improved electronic technology, occurring at a time of industry need.

Sonic instruments are much improved, their answers have been proved right, they have allowed thousands of logs to be tested, and the results put numbers to what the industry suspected – the timber to be dealt with in the foreseeable future is extremely variable, both tree to tree and within a single tree.

All of the early sonic instruments, many of which are still used, derive from “stress wave timers”, which I believe were originally made to detect rot in utility poles. The time taken for an elastic impulse from a blow on the side of a pole to appear at the opposite side of the pole was measured, and poles ranked. Decayed timber produced long transit times, or low speeds. It was a short step to using such instruments to measure the speed of “sound waves” along a sample such as a log, and relate the speed to elastic modulus via the beguilingly simple expression

MOE = density x speed squared

Two problems are implicit here. First, this equation applies to plane waves of compression moving along a rod-like structure, and these are not necessarily dominant in a log hit by a hammer. In such waves, all elements in a cross section move identically, and parallel to the sides of the rod. The waves radiating near the impact point are not plane, and move considerably faster. Second, the accuracy with which the time delay of a pulse can be measured is limited, but it is important, because the modulus computed depends on the square of the speed.



Because answers from this equation frequently differed from values obtained by bending, we seem to have accepted the existence of both a static modulus, and a dynamic one (i.e. one measured by the rapid stretches and compressions of the sound wave). The reason for the difference was not questioned. It was assumed that vibrating something fast might lead to a physically different spring constant than if the shaking was slow. This is not an unreasonable proposition.

The disturbance that spreads from a blow is not described by the equation above until it has propagated a long way, probably well beyond the length of the sample. But if you let the impulse bounce back and forth (log ends are good reflectors of sound waves), it soon becomes a plane wave, and the speed measured is lower than that found on the first pass. Furthermore, the modulus calculated from this resonance speed agrees well with the modulus found from static bending. The need for echoes is the reason for the emphasis on cut ends in the opening sentences.

My experience with pine, and to a limited extent with eucalypts, is that the bending modulus is usually from 90 to 100% of the acoustic value, on samples several metres long. The acoustic modulus is the average over the entire length. The resonating sound wave has a length twice that of the sample, so it is not surprising that small defects such as knots have little effect. But as point defects, they have the potential to have a significant effect on a bending measurement, and this no doubt is part of the reason that the bending value can be a little lower.

There is no clear evidence that after removing the effect of knots etc, acoustic and bending modulii differ.

On ASTM (American Society of Testing Materials) test clears, 20x20x300mm, colleagues have found excellent agreement between sonic and bending values. The chief issue there in fact was that the position of the few latewood bands found in locally grown timber can make a significant difference between radial and tangential stiffness. The acoustic value tends to split the difference!

The ASTM samples resonated at about 8kHz, so stressing periods were a small fraction of a millisecond, while the bending measurement might take a minute. The ratio of the stressing times is half a million. Perhaps we should abandon mention of a dynamic modulus and just call it the MOE.

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Measurements on live trees of course cannot be made by resonance methods because there are no well defined reflecting ends, though we have certainly tried bouncing trees up and down with a sledge hammer to try and start resonances. We have recently made progress in interpreting single pass, time of flight records on short sections of trunks, and I think that assessment of growing trees will be possible.

Because the sound waves involved in resonance are long, almost any cut will provide a perfectly adequate reflection. A broken end also reflects reasonably well, and the main difficulty is guessing the effective length at which the reflection is occurring. It's a forgiving measurement. In journals one sees researchers sounding samples supported by air bags, but while this may improve signal quality, perfectly adequate signals can be obtained from logs on bearers, on firm ground, half buried in mud, and in stacks (but care is needed in interpretation there – they do couple).

Twenty years ago, the computing power to make a portable resonance analyzer did not exist. It does now, and in New Zealand we have seen Carter Holt Harvey's Hitman, shown in Fig. 1, which combines functions into one package, and Fletcher Challenge Forest's SWAT which integrates a data capture package with an industrial computer. The early, single pass, stress wave timer is a much simpler item.

Resonance instruments give the same answer as each other, because repeating echo times are being measured, and this doesn't depend on a detector threshold setting. But there is a practical issue which makes the case for resonance instruments industrially overwhelming. Unlike stress wave timers, the measurement is done from only one end, so there is no cabling problem. Running cables along a stem or across a stack is out of the question.

Acoustic measurements are on a solid foundation. We also know from many pulping trials that stiff wood has long fibres. Since these have a low microfibril angle, acoustic measurements let us into the hierarchy.

Weyerhaeuser Corporation has used acoustic maps of timber to predict differential shrinkage and warp via the microfibril angle variations deduced from the sonic

Fig. 1: Carter Holt Harvey's Hitman system combines functions into one package.

measurements. It is remarkable that a single hammer blow can give information on a nano-scale parameter like microfibril angle, something one would normally need X-ray diffraction to measure.

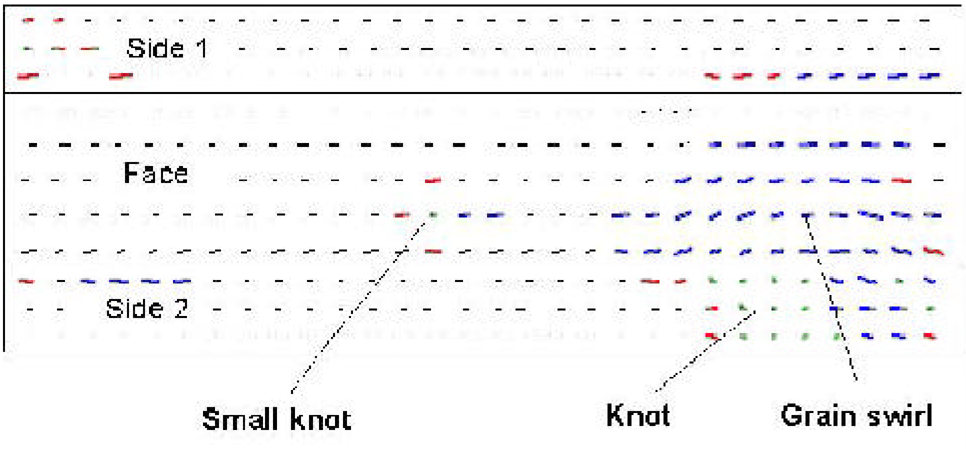

Fig. 2: Grain map of three sides of a 100x50 sample, 600mm long. The lines indicate the grain direction, and their lengths are proportional to the fibre length. Fibre length is greater at the top of the wide face than the bottom.

So much for the technical issues. We have a robust and believable measuring system. Industry acceptance is the other side of the coin. As a newcomer I was surprised to find that wood stiffness and the fibre properties it implies didn't seem to have received much attention until the last ten years, and even now, many people (such as the investing public) have little idea about what may lurk behind the bark of a carefully tended, and pruned butt log, growing on a fertile site.

The problem of implementation is an economic one. Every company and country has different logging practices, and there is no universal model for capturing the benefits of our ability to classify logs into fibre types. Progress is happening in Australasia and in USA, but it is slow. In the field of engineered products such as LVL, the ability to quantify raw material is a significant advantage and the acceptance of sonics is faster.

Advances are being made in the ways in which acoustic measurements are made, and this may make the adoption of the technique simpler.

Producing sound waves by hammer blows is convenient in the forest, but not ideal. For example, a blow on a wet log produces most energy around 1kHz. Too bad if the resonances sought lie outside that range. It is better to apply a controlled signal to the sample. Sensitivity can be greatly enhanced because if the form of the signal being applied is known, you know what to look for. Measuring equipment which uses a controlled signal source has been made by IRL. Initially the impetus was to be able to measure samples too small to be hit satisfactorily. Sticks such as 20x20x300mm ASTM samples or small bolts were excited in non-contact mode by sound from a speaker. There is no reason in principle why in factory situations, logs could not be remotely excited, which simplifies the mechanics of an installation.

What other wood quality tools lie ahead?

A potentially powerful inspection technology is tracheid scatter. When a small but intense light spot hits a wood sample, it is scattered along, rather than across tracheids, because they act as light pipes. The small incident spot spreads into a grain-aligned ellipse a few millimeters long. The scatter works as well on wet, rough sawn wood as dried and planed material. It complements sonic measurements, as it enters the stiffness-fibre length-MFA hierarchy above by indicating fibre length and direction. And like sonics, it was explored 20 years ago, but perhaps was too difficult for the sensors then available, and the industry problems were different.

At IRL we have a programme aimed at quantifying scatter measurements. The light-guiding properties of tracheids make this a plausible aim. If predicting wood stability is to be an issue of the future, I believe that tracheid scatter systems will have a major role in automated inspection systems. Fig. 2 shows a step in this direction; a small length of wet sawn timber which was scanned on three sides. From the light scatter patterns, grain swirls, fibre length changes, knots, and the probability of twist upon drying have been identified.

The basics of sonic methods are in place and proven. We have moved past tentative statement like "velocity correlates with stiffness". Acoustic classification is routinely being done on stems in NZ to route them to appropriate end use. I am optimistic that we will be able to grade live trees in the near future. The issue is how one can incorporate segregated feedstock into the production lines of mills which didn't expect it to be graded. New versions of acoustic sounders should help.

More distantly, tracheid scatter will prove to be a robust method of probing wood at the fibre level. Some obstacles here are simply our ability to process fast enough, while other questions require more study of the ducting of light within wood fibres.