Using acoustic tools in forestry and the wood supply chain

The demands for sustainably produced wood as a raw material for a variety of end uses is placing increased pressure on the forest resource in the UK. Knowledge of the timber properties of trees and logs is important to ensure that harvested wood is directed to its most appropriate end use. Current harvesting practice in the UK means that trees are often felled, processed and dried before the timber is strength graded by machines at the sawmill. This process can be inefficient if timber destined for structural uses is later found to be unsuitable; downgrading may incur significant financial and environmental costs. The use of acoustic technology to predict the mechanical properties of timber is a well-established practice overseas. Recent advances in technology and the development of portable instruments mean that wood can now be assessed in standing trees before they are felled. Trials in the UK have shown that it is possible to relate measurements of acoustic velocity in standing trees and logs to the mechanical properties of timber cut from them. This gives the potential to segregate material for different end uses in the forest, at the roadside or in the sawmill.

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Technical Note

Introduction

There is a growing demand on the forest resource in the UK to supply wood products for a variety of end uses – ranging from construction timber to raw materials for the bioenergy sector. In 2008 the amount of wood harvested from conifer plantations was around 8.4 million green tonnes. To maximise the economic and environmental benefits of British forests it is important that harvested material is directed towards the most appropriate end uses, based on the properties of the timber. The majority of softwood timber currently produced in the UK (64%) is sent to sawmills and approximately one-third of these logs are processed into construction timber. This is a key market given its current size (approximately 6 million m^3 per annum) and value, and the likelihood that it will increase in the future as a result of the continuing move towards a more sustainable built environment.

Timber for construction

As with all materials used for construction, timber for structural uses is classified by its physical and mechanical properties. A European Standard (BS EN 338:2003) sets out the system of strength classes for structural timber. The Standard provides characteristic strength and stiffness properties and density values for each class and the rules for the allocation of timber populations (combinations of species, source and grade) to the classes. Eighteen classes are defined: 12 for softwoods and poplar (prefixed C) and 6 for hardwoods (prefixed D). The softwood strength classes range from C14 (weakest) to C50. The hardwood strength classes range from D30 to D70. These numbers represent the characteristic bending strength of the timber. The material properties associated with each of these strength classes are used by engineers when designing timber structures, for example, to Eurocode 5 (BS EN1995-1-1: 2004).

C16 is the minimum strength class most commonly used for general construction use and timber from conifers grown in the UK can typically attain or exceed this grade. However, wood properties can vary between and within stands, trees and logs – even if the wood is from trees of same species. Up to 10% of sawn timber currently fails to meet the minimum requirements of the C16 strength class. Downgraded timber is sold at a lower price for alternative non-structural uses. This increases operating costs as trees are often processed and the timber kiln-dried before wood properties are assessed and the timber strength graded. There is also the cost and environmental impact of unnecessary transport to sawmills.

In order to reduce the proportion of timber that fails to meet the requirements for the C16 grade, a means of identifying the trees and logs which are likely to produce structural timber is required. The earlier in the wood supply chain material can be segregated, the more options there are for directing it towards an appropriate end use – based on its properties and the prevailing market requirements. Currently, the segregation of trees and logs is often only based on visual characteristics such as diameter and form. While this generally provides valuable information on the volume of timber that can be recovered, it is not a good indicator of the physical or mechanical properties of the timber.

Acoustic technology

Acoustic tools are a non-destructive method of predicting the physical and mechanical properties of timber and wood-based materials. They work by measuring the propagation of stress waves (see Box 1) through wood. A wide range of instruments are now available for use in both field and laboratory environments. Recent advances in technology have lead to more robust systems with increased accuracy and the development of a range of portable devices. Although some of these tools were originally designed for measuring decay in wooden structures, such as bridges and utility poles, it was recognised that the technology could have forestry applications – particularly for assessing wood stiffness in standing trees and the suitability of timber for structural uses.

Figure 1 Segregation of logs in the forest is currently often based on visual characteristics such as diameter and form.

Box 1 – How acoustic tools work

Acoustic tools measure the speed at which an induced sound or stress wave travels through a sample of wood. The velocity of a stress wave is related to the stiffness of the material, known as the 'modulus of elasticity' (MoE) and to its density. Wood stiffness or MoE can be predicted from stress wave velocity and density using the equation:

$$MoE = \rho V^2$$

where MoE is the modulus of elasticity (measured in N m^{-2}), ρ is the density of the wood (measured in kg m^{-3}) and V is the velocity of the stress wave (measured in m s^{-1}). Wood density is generally assumed to be constant between and within trees for measurements made on standing trees and freshly felled logs, allowing material to be segregated using velocity values alone. The velocity of the stress wave has to be measured and this can be done in two ways: using either the time-of-flight method or the resonance method.

Time-of-flight method

This method is used to take measurements on standing trees. The approach involves simply timing a stress wave as it travels over a fixed distance through a tree. Velocity can be calculated by dividing the distance travelled by the stress wave by the time taken. This approach is often referred to as the 'time-of-flight' or 'pitch-and-catch' method. Figure 2 shows an example of the type of tool used.

Resonance method

This method is used to take measurements of stress wave velocity on felled logs and sawn timber. The approach is based on the principle that a stress wave introduced into a wood sample (e.g. a log or piece of sawn timber) will cause the sample to vibrate at its natural (or resonant) frequency. The velocity of the stress wave can be calculated from the frequency of the vibration and the length of the log or wood sample. Figure 3 shows an example of the type of tool used.

Wood stiffness and strength

The MoE calculated by these methods is referred to as the *dynamic* modulus of elasticity. It is higher than the *static* modulus of elasticity obtained from traditional bending tests but the two are highly correlated. The stiffness of wood (MoE) and the strength of wood (MoR) are correlated and this is the principle used in strength grading machines. Therefore, because acoustic tools provide a measure of MoE they also provide a good estimate of wood strength.

Figure 2 Portable acoustic tool for measuring stress wave velocity in standing trees using the time-of-flight method.

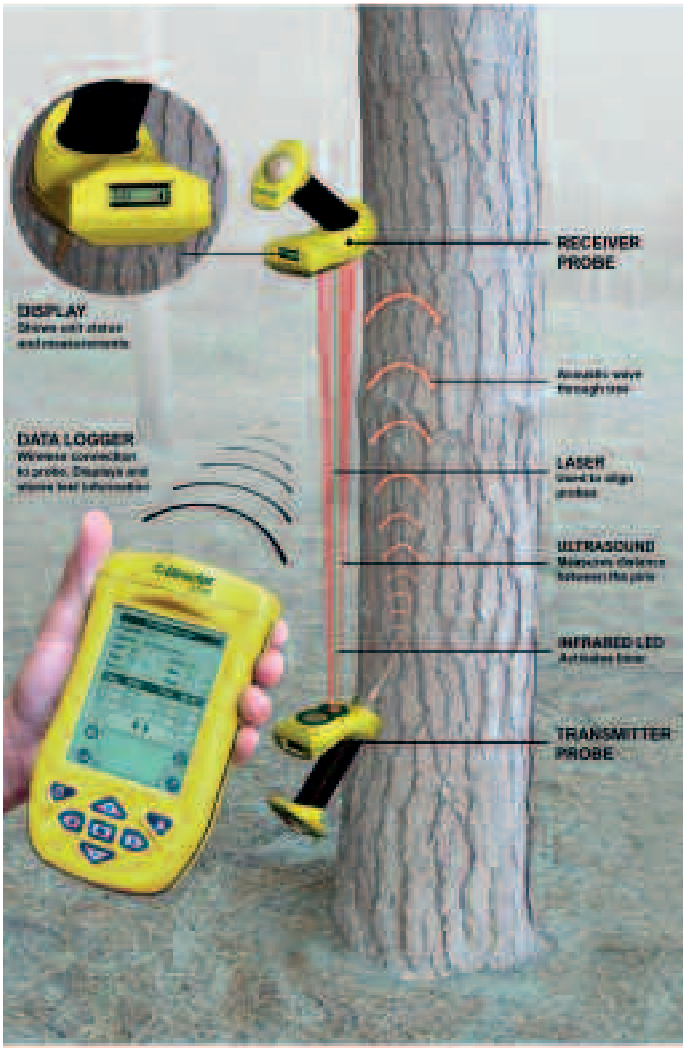

Figure 3 Portable acoustic tool for measuring stress wave velocity in felled logs and cut timber using the resonance method.

Applications in forestry

Acoustic tools have been used by forest industries overseas for a number of years but the technology has only recently been taken up by the UK forestry sector. It has already shown to be effective as a means of predicting the mechanical properties of timber, and the tools are now used to assess the potential quality of wood in standing trees and felled logs in the forest as well as sawn timber in the mill. In addition to the use of acoustic technology to assess the suitability of trees and logs for structural timber, research has shown that acoustic velocity measurements can also be used to identify material suitable for other end uses, such as the production of veneers or pulp and paper, and to measure changes in the moisture content of log stacks. Measurements on standing trees can also be used to help understand the effects of environmental and site factors on wood properties, assess the impacts of different silvicultural treatments, and to select trees for breeding programmes.

Hand-held tools are used for taking measurements on standing trees and felled logs, while larger-scale, automated systems are used for segregating logs entering a sawmill and grading sawn timber leaving a mill. Examples of commonly available acoustic tools are given in Table 1, although this list is not exhaustive. A prototype acoustic system is also being developed which is capable of being mounted on the felling head of a harvester.

Standing trees

Acoustic tools for taking measurements on standing trees are based on the time-of-flight method (Box 1). The instrument generally consists of a hand-held data logger and two probes (a transmitter probe and a receiver probe). The probes are driven into the outer 20–30 mm of the tree at a known distance apart, and so that they are vertically aligned (Figure 4). The stress wave is generated by tapping the transmitter probe which also starts a timer. The timer is stopped when the wave reaches the receiver probe. The time taken for the wave to travel between the two probes is measured by electronics in the receiver and stored on the data logger.

Figure 4 A portable acoustic tool being used to measure stress wave velocity in a standing tree.

Table 1 Examples of acoustic tools and their applications.

Tool	Application(s)	Manufacturer	Website
ST-300	Standing tree	Fibre-gen, New Zealand	www.fibre-gen.com
Sylvatest Duo	Standing tree	CBS–CBT, France	www.sylvatest.com
TreeTap	Standing tree	University of Canterbury, New Zealand	www.research.canterbury.ac.nz
TreeSonic	Standing tree	Fakopp Enterprises, Hungary	www.fakopp.com
IML Hammer	Standing tree	Instrumenta Mechanic Labor GmbH, Germany	www.iml.de
LG-640	Felled logs/sawn timber	Fibre-gen, New Zealand	www.fibre-gen.com
RLG	Felled logs/sawn timber	Fakopp Enterprises, Hungary	www.fakopp.com
HM-200	Felled logs/sawn timber	Fibre-gen, New Zealand	www.fibre-gen.com
Dynagrade	Sawn timber	Dynalyse AB, Sweden	www.dynagrade.com
ViSCAN	Sawn timber	Microtec, Italy	www.microtec.eu
MTG	Sawn timber	AB Brookhuis Micro Electronics, Netherlands	www.brookhuis.com
PUNDIT	Laboratory	CNS Farnell, UK	www.cnsfarnell.com
Grindosonic	Laboratory	J W Lemmens, Belgium	www.grindosonic.com/en/

Felled logs and sawn timber

While time-of-flight acoustic tools can be used on felled logs and sawn timber, measurements are generally made with tools based on the resonance method (Box 1). The instrument comprises an accelerometer or microphone that measures the vibration frequency of the timber specimen. The specimen is made to vibrate by tapping it on the transverse face. (Figure 5). These instruments are generally only used on specimens which have a cut surface, e.g. logs, sawn timber, panels and wood composites, and a large longitudinal dimension relative to the transverse dimension. These characteristics are necessary to ensure that the specimen can be made to vibrate longitudinally and this vibration to be detected.

Application of results

Measurements made using acoustic tools are used to calculate dynamic modulus of elasticity, which is generally higher than static modulus of elasticity determined from bending tests. However, laboratory tests show that there is a very strong relationship ($R^2 > 0.9$) between dynamic modulus of elasticity and its static equivalent for small, defect-free samples and sawn timber. This is the basis for using acoustic machines for in-line grading of sawn timber. In addition, these results indicate that portable resonance-based tools can be used to predict the mechanical properties of large-section timber and poles which would otherwise only be visually inspected.

Figure 5 Portable acoustic tool for measuring resonance.

Time-of-flight and Resonance methods

Tests to compare the results of time-of-flight measurements taken on standing trees and resonance measurements taken on logs cut from the same trees have shown that there is a strong relationship between the stress wave velocities measured by the two methods. The correlation between the two measurements indicates that it is possible to make robust estimates of wood stiffness in the forest before a tree is felled.

Variations between acoustic tools

The results from different acoustic tools designed to measure stress wave velocity using the time-of-flight method vary due to the different thresholds for triggering the start and end of the measurement. This means that any velocity thresholds used for segregating standing trees in the forest are likely to be instrument specific. A formal comparison of different time-of-flight tools is currently being undertaken to better understand and quantify these differences.

The results from different acoustic tools designed to measure stress wave velocity using the resonance-based method should give the same results as each other. For example, tests have shown that there are good correlations between measurements on felled logs made with the HM-200 hand-held acoustic tool and the recently developed LG-640 system which is designed for use on logs entering a sawmill.

Future directions

To allow the operational use of acoustic tools in the forest-to-mill wood supply chain, the different tools that are available need to be carefully tested against each other and the results compared with the mechanical properties of the resulting sawn timber. This will allow individual thresholds to be set for each machine, allowing segregation of trees and logs for different end uses. In addition, the integration of such tools within current management, harvesting and mill operations needs to be carefully planned and tested on an industrial scale. Such work is underway and will be reported on at a future date.

Ideally, the earlier in the chain the segregation of timber can be made the more flexibility there is for determining the cutting patterns used and the final end use for the timber. Trials are underway to fit acoustic technology to standard harvester heads in order to segregate trees during harvesting. The system uses a method similar to that used by hand-held tools for measuring standing trees, but the measurement is carried out automatically as the tree is felled or cross cut. This allows the operator to modify the cutting pattern according to the acoustic velocity and to cut log lengths that are most appropriate for the stiffness of the timber and the proposed end use.

There is a need for further tests on machines that are used for in-line grading of sawn timber to both gain approval to European Standards and to determine the settings for a wider range of species and grades. In addition, the use of hand-held acoustic tools for assessing large-dimension timber, currently assessed visually, requires further investigation. Together these initiatives would allow higher value use of the UK minor species resource.

Useful sources of information

British Standards

BS EN 338: 2003
Structural timber. Strength classes.

BS EN 1995-1-1: 2004
Eurocode 5: Design of timber structures. General. Common rules and rules for buildings.

Publications

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