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Advanced Sorting Technologies for Optimal Wood Products and Woody Biomass Utilization

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***Abstract*— Forest materials represent great potential for advancing our goals in the 21st century for sustainable building, energy independence, and carbon sequestration. A critical component of an improved system for producing bioproducts and bioenergy from forest materials is the ability to sort trees, stems, and logs into end-product categories that represent their highest potential values. Nondestructive testing and evaluation technologies have been explored by scientists, engineers, and managers around the world for their ability to assess wood and fiber properties of individual trees, stems, and logs. Strong relationships were found exist between various acoustic measurements on trees/logs and fundamental wood properties such as microfibril angle, density, and various physical and mechanical properties. Commercial field-ready tools are now available that are capable of sorting this biomass based upon fundamental properties that determine product potential. The research results can be applied at a number of stages in the operational value chain, from timberland through to the processing site. This paper introduces an array of acoustic tools for forest operations and demonstrates their ability to sort forest materials into categories that are suitable for their optimal uses, such as high value structural products, advanced composites, pulp and paper, and biofuels.**

Keywords - Acoustic technology, biomass, logs, wood quality, sorting, trees

I. INTRODUCTION

Acoustic technologies have been well established as material evaluation tools in the past several decades, and their use has become widely accepted in the forest products industry for on-line quality control and products grading [1]. Recent research developments on acoustic sensing technology offer further opportunities for wood manufacturers and forest owners to evaluate raw wood materials (standing trees, stems, and logs) for general wood quality and intrinsic wood properties. This provides strategic information that can help make economic and environmental management decisions on treatments for individual trees and forest stands, improve thinning and harvesting operations, and efficiently allocate timber resources for optimal utilization. For example, the information could be used to sort and grade trees and logs according to their suitability for different end-uses, such as structural products, advanced composites, pulp and paper and bioenergy. Another example is to determine the relationships between environmental conditions, silvicultural practices and wood fiber properties so that the most effective treatment can be selected for future plantations for desired fiber quality. Today, the precision of acoustic technology has been improved to the point where tree quality and intrinsic wood properties can be predicted and correlated to the performance and economic values of the final products. With continuous advancements and refinements, this technology could assist in managing wood quality, assessing forest value, and improving the timber quality of future plantations.

II. ASSESSING LOG QUALITY

It is well recognized that the variation in wood and fiber properties is enormous within a pile of logs that has been visually sorted for similar grade. The same is true for logs from trees of the same age and from the same forest stand [2]. There are major commercial benefits to be gained by assessing the wood properties at log level and optimizing the use of the resources through appropriate log sorting. The ability to improve log sorting with resonance based acoustic methods has been well recognized in the forest products industry [2-7]. This technology is based on the observation of hundreds of acoustic pulses resonating longitudinally in a log and provides a weighted average acoustic velocity. Because the modulus of elasticity (MOE) of the log is simply equal to density times the acoustic velocity squared, the technology is basically measuring fiber properties that influence macro properties such as stiffness, strength, and stability. The challenge is to interpret what the log is "saying" and translate this information into meaningful values [8].

A. Sorting Logs for Lumber Quality

Research has shown that log acoustic measures can be used to predict the strength and stiffness of structural lumber that would be produced from a log. To validate the usefulness of the resonance acoustic method for a practical log sorting process, Wang and Ross (2000) conducted a mill study and examined the effect of log acoustic sorting on lumber stiffness and lumber E-grades. After acoustically testing 107 red maple logs, they sorted the logs into four classes according to acoustic velocity [9]. **Figure 1** illustrates the average lumber MOE for each log class, with a significant differentiation and clear trend between the log acoustic classes. They further compared log acoustic classes to lumber E-grades and found a good relationship between them. Logs that have a high acoustic velocity contain higher proportions of high-grade lumber. A study in New Zealand revealed similar results when presorting unproved logs of radiata pine into three acoustic classes [10]. The logs with the highest acoustic velocity (the top 30%) produced timber that was 90 percent stiffer than that from the group with the lowest velocity (the bottom 30%). In a practical log-sorting process, companies can achieve benefits by developing a sorting strategy based on the log sources and desired end products.

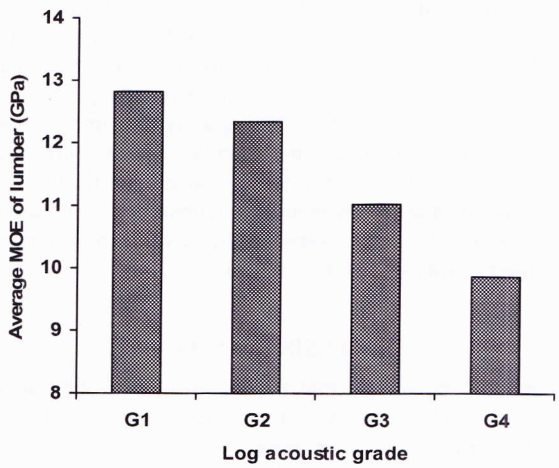

Figure 1. Log acoustic grade versus average MOE of lumber.

Currently, the companies implementing acoustic sorting strategies measure only the velocity of acoustic waves and segregate logs into velocity groups using predetermined cut-off velocity values. Appropriate cut-off acoustic velocity values can be determined for either selecting the highest quality logs for superior structural applications or isolating the low grade logs for nonstructural uses. **Figure 2** demonstrates the increasing yield of structural grades of lumber with increasing acoustic velocity of logs processed, as measured at two New Zealand radiata pine sawmills [11].

B. Sorting Logs for Veneer Quality

Log acoustic measurement has also been successfully used to assess the quality of veneer obtained from logs. **Figure 3** illustrates the relationship between acoustic velocity for Southern pine log batches (10 percentile groups from log sample) and the average ultrasound propagation time (UPT) of veneer peeled from the logs [11]. UPT is the elapsed time for ultrasound to travel between fixed roller transducers on a commercial ultrasound veneer grader.

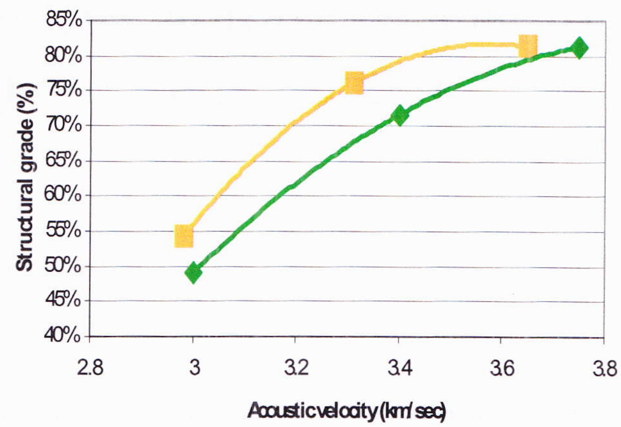

Figure 2. Log acoustic velocity versus yield of structural grades for two New Zealand radiate pine sawmills.

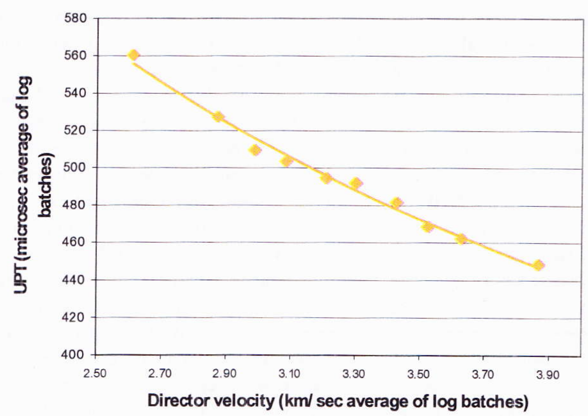

Figure 3. Acoustic velocity of southern pine log batches versus the average ultrasound propagation time (UPT) of veneer from the logs.

C. Sorting Logs for Pulp and Paper Quality

Quantify the raw materials going into the paper mill is one of the largest thrusts in the paper industry. Information on fiber characteristics of pulp logs is needed to determine the fits to final paper products. Acoustic technology offers more effective means of sorting pulp logs with particular fiber characteristics than the use of basic density. Albert et al. (2002) have tested the hypothesis that the acoustic measures of pulp logs are linked to the fiber characteristics and paper properties [12]. In a trial with 250 radiata pine peeler cores, they sorted the cores into 18 classes using acoustic velocity. Subsequent pulping and testing demonstrated that fiber length, wet strength, and various handsheet properties varied systematically. The acoustic velocity of the peeler cores was found strongly related to the length-weighted fiber length and the wet zero-span tensile strength of the fibers from the peeler cores. In a larger mill study with 2,247 radiata pine logs, Bradley et al. (2005) confirmed that acoustics could segregate logs into groups that perform very differently in terms of pulp properties when refined to a given freeness or at a certain energy input [13]. At a given target freeness, there was a 20 percent difference in energy requirement between the lowest and highest velocity logs for a given specific energy. They conclude that acoustic sorting and subsequent reblending has great potential to reduce fluctuations in pulp quality of the mill output.

D. Monitoring Moisture Changes in Log Stocks

A further application of acoustic methods has been identified for monitoring changes in moisture content of freshly harvested logs as high as 150 percent down to an air-dry state of 30 to 40 percent. Moisture content (MC) is important for fuel wood supplies to determine at what stage a log should be chipped and burned, as well as for certain mechanical and semi-chemical pulping processes where MC is critical for effective processing. Traditional sampling methods are cumbersome and time-consuming, and there is no convenient portable tool capable of measuring MC at these levels, as the standard electrical conductivity or impedance methods become inaccurate at MCs above fiber saturation point. Yet the defined relationship between acoustic velocity and green density enables the evaluation of changes in density caused by loss of moisture simply by monitoring the average increase in acoustic velocity that is observed as MC and associated green density decline with time.

III. ASSESSING TREE QUALITY

The applicability of using acoustic waves to assess the intrinsic wood properties of standing trees has been validated by many research works around the world [14]. A typical approach for measuring acoustic velocity in standing trees involves inserting two sensor probes (transmit probe and receiver probe) into the sapwood and introducing acoustic energy into the tree through a hammer impact. Unlike the resonance method which obtains the weighted average velocity by analyzing whole wave signals transmitted between the ends of a log, the standing tree acoustic tool measures time-of-flight (TOF) for a single pulse wave to pass through the tree trunk from the transmit probe to the receive probe.

A. Measuring Wood Properties of Standing Trees

With simple velocity measurements, individual trees and stands can be evaluated and sorted for their structural quality and stumpage value. In a series of studies of evaluating tree quality in terms of structural performance, Ikeda and Kino (2000) found highly significant correlations between tree velocity and MOE of logs and square sawn timbers [15]. Through several mill trials, Huang (2000) demonstrated that trees with the potential to produce high and low stiffness lumber can be identified by tree acoustic velocity alone [16]. The upper 15 percent and lower quartile of the population can be sorted by high and low velocity respectively. Recent wood quality research has shown that a range of wood and fiber properties can be predicted through a simple acoustic measurement in standing trees. **Figures 4** and **5** show the relationships between tree acoustic velocity and the MOE and microfibril angle (MFA) of core samples from the trees measured by x-ray densitometry, diffractometry, and image analysis [14].

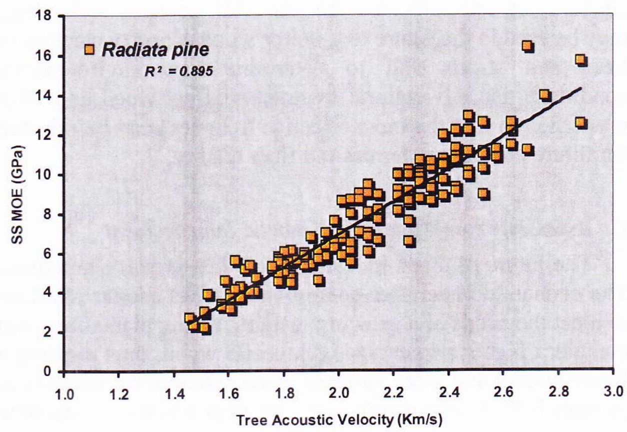

Figure 4. Relationship between tree acoustic velocity and MOE of the core samples measured using Silvascan-2 for radiate pine.

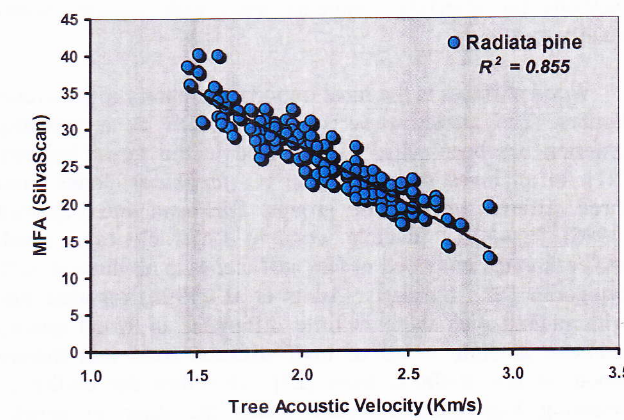

Figure 5. Relationship between tree acoustic velocity and microfibril angle (MFA) of the core samples measured using Silvascan-2 for radiate pine.

B. Assessing Silvicultural Treatment Effects

Quality and intrinsic wood properties of trees are generally affected by silvicultural practices, especially by stand density. Some silvicultural practices not only increase the biomass production of trees but also might improve the quality of the wood in trees. Nakamura (1996) used ultrasonically induced waves to assess Todo-fir and Larch trees and observed significant differences in acoustic velocities and acoustic-determined MOE for trees in forest stands at different locations and trees of different ages [17].

Wang (1999) examined the effect of thinning treatments on both acoustic and static bending properties of young growth western hemlock and Sitka spruce trees obtained from seven sites in southeast Alaska [18]. He found that trees with higher acoustic velocity and stiffness were mostly found in unthinned control stands and stands that received light thinning, whereas the lowest values were found in stands that received heavy and medium thinning. These results were encouraging and indicated that the TOF acoustic technology may be used in the future to monitor wood property changes in trees and stands and to determine how environmental conditions and silvicultural treatments affect wood and fiber properties so that the most effective treatment can be selected for future plantations for desired fiber quality.

C. Assessing Young Trees for Genetic Improvement

The future of forest industry lies in fast-grown plantations. The economic imperative continuously seeks shorter rotations to meet the needs of a growing market. Young plantations will contain a higher percentage of juvenile wood, thus creating a lower quality and more variable wood resource for industry to process [19]. Consequently, genetic improvement of juvenile wood properties is now receiving attention and getting higher priority in research. To help capture genetic opportunities, there is a need to determine wood quality at an early age [20]. The major challenge in operational tree improvement programs is to develop rapid and cost-effective assessment methods for selecting candidate trees with superior wood quality trait.

Wood stiffness is the most important property of structural lumber. The attractiveness of using MOE as a breeding criterion has been widely recognized in the forest industry [21]. In an investigation of sugi (*C. japonica*) clones from three different growth-rate groups, Hirakawa and Fujisawa (1995) found that juvenile wood in stiffer clones is much stiffer than mature wood of less stiff clones in all three growth categories [22]. Similarly, Addis et al. (1998) reported that with radiata pine there is little difference in wood quality between juvenile wood of high stiffness trees and mature wood of low stiffness trees [23]. Therefore the ability of selecting high stiffness trees opens the door to genetic improvement for future plantations. With the ability of nondestructively assessing the wood properties of standing trees and raw log materials, acoustic methods have quickly been recognized as a useful tool in tree breeding programs [2, 5]. Lindstrom et al. (2002) investigated the possibility of selecting *Pinus radiata* clones with high MOE and found that acoustic measurement yielded results similar to traditional destructive and high cost static bending methods [20]. They conclude that acoustic tools could provide opportunities of mass screening for stiffness of fast-grown radiata pine clones at a very early age.

D. Evaluation of Plantation Resource for Wood Quality

In applying acoustic technology to a plantation resource, typically a number of stages will be considered. For example, a program to define wood quality for structural applications could have the goal of targeting extraction of greatest commercial value from the forest resource available, while recognizing the need to solve the problem of relatively low-stiffness wood in younger stands of much of the softwood plantation resource coming available in many countries. Stages in a wood quality assessment program using acoustic hand tools for trial work and stand selection could include the following:

1) Undertake a forest survey by mapping acoustic velocity at stand level across a range of topography, altitude, soils, ages, and silviculture (sample approximately 50 stands);
2) Confirm the relationship between average standing tree velocity and average log velocity by felling 20 to 30 trees on each of 15 or more sites. Confirm velocity pattern up tree on a sub-sample of these;
3) Saw a sample of logs and confirm static MOE and MOR of lumber, and grade outturn, relative to recorded log and standing tree velocity;
4) Correlate static MOE with predicted MOE from commercial testing devices (x-ray density, acoustic, mechanical bending).

By following this approach, the plantation resource can be characterized according to stiffness to enable management, planning, harvesting, and wood processing to be carried out in a way that optimizes stiffness-related value from the resource.

IV. OPERATIONAL APPLICATION OF ACOUSTIC TECHNOLOGY

As operational application of acoustic technology is considered, there is a recognized need for the technology to be applied at a number of stages in the operational value chain, from timberlands through to the processing site. New tools have been developed or are under development to suit each specific application. Standing tree assessment is relevant for tree breeding, pre-harvest assessment (PHA) for forest or stumpage valuation, and decision support at time of thinning, where trees cannot be cut. The harvesting processor application provides decision support for log-making, as well as collation of data for subsequent forest management, harvest planning, and valuation. Felled stems can be tested to assist in optimization of value capture in log-making, while logs can be assessed for ranking of average wood quality (stiffness and related characteristics), or segregated for supply to different customers or processing options. Automated on-line log testing is relevant to valuation of log supplies, ranking of log supply sources, prediction of MSR yields for output planning, as well as providing a very efficient means for segregation of logs based on quality and suitability for different customers or processing options.

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