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Technical Note

The potential of in-forest segregation using an acoustic tool on a harvester head

Author/s: John Moore, Peter Carter, Nigel Sharplin, Marco Lausberg

Corresponding author: john.moore@scionresearch.com

Summary: Portable acoustic tools have been used in many regions of the world to segregate trees, logs and wood products on the basis of their estimated modulus of elasticity. Such segregation is important in the wood supply chain for products such as structural lumber and laminated veneer lumber, where wood stiffness is the key performance characteristic. Recently, a prototype system has been developed consisting of a time-of-flight acoustic tool incorporated into a processing head on a harvesting machine. In this technical note, we describe this technology more fully and present the results from a trial looking at the efficacy of such an approach for selecting logs for the production of laminated veneer lumber.

In the trial, stress-wave velocity was measured on a sample of 119 logs using the HM200 and PH330 tools. Log size and geometry was also measured on these logs, which were then processed into veneer sheets at Nelson Pine Industries' laminated veneer lumber mill. Different segregation options were explored that delivered batches of logs with average stiffness values equivalent to current in-mill specification that are based on a mean stress-wave velocity measured with the HM200 tool. Results from this trial showed that segregation using this technology could deliver a batch of logs to the mill with the same average veneer stiffness as a batch delivered under a specification that 90% of logs need to have a manually tested HM200 value greater than 3.1 km s^{-1}. While the automated on-head approach would result in a 17% reduction in veneer log yield compared against segregation at the mill using the HM200 tool, such HM200-based segregation would incur substantial costs associated with logs that are cut and delivered to an LVL mill, but are subsequently downgraded because they are not stiff enough. Compared to the base case of no segregation, the automated harvester-head approach delivered a yield of 63% of veneer logs from the sample stand. This would enable substantial extra volumes of veneer grade logs to be extracted from the current resource of mid stiffness stands through in-forest segregation.

Introduction

Wood stiffness or modulus of elasticity is a key performance attribute for products such as structural lumber and laminated veneer lumber (LVL). The manufacturers of these products require a raw material supply that has adequate stiffness in order to get acceptable yields of their target products[1, 2]. Downgrading large amounts of material in the mill can be very expensive as logs may be the wrong length for other non-structural uses. Therefore, approaches are needed for identifying suitable trees for these uses as early as possible in the supply chain. This enables decisions to be made on the appropriate log lengths to be cut from such trees and will ensure that the mills obtain suitable logs. Such information can also be used by forest managers to improve the value obtained from harvested stands.

Acoustic non-destructive tools enable modulus of elasticity to be estimated on standing trees, logs and for products such as structural lumber and veneers[3]. These tools are commonly used to grade material in structural lumber and LVL mills[4]. Resonance-type acoustic tools such as the HM-200 (Fibre-gen, New Zealand) have been used to segregate logs in a range of applications and in-line tools based on this principle have been installed in log in-feed lines in several mills around the world. Studies in both New Zealand and abroad have shown that there is a moderate to strong correlation between modulus of elasticity estimated on logs and end-product performance[2, 5-9]. However, one of the drawbacks of

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this approach is that the decision to cut a log of a certain length has already been made. Logs that are found to have a low modulus of elasticity may be the wrong length for alternative processing streams, resulting in substantial loss of value.

An alternative approach is to estimate modulus of elasticity on standing trees and to use this information to determine how the stem should be best merchandised into logs. Fibre-gen has been developing an acoustic tool (PH-330) that is incorporated into a harvester head[10]. This tool enables log bucking decisions to be made based on external attributes such as diameter and sweep along with an estimate of the dynamic modulus of elasticity. In this technical note we describe this technology and provide results from a study examining its application to in-forest segregation for veneer production.

PH-330 Acoustic Tool

The PH-330 is a time-of-flight acoustic tool that is incorporated into a harvester head – in this case either a Warratah 624 or 626 unit (Figure 1). The unit consists of transmit and receive probes that penetrate the bark and the time taken for a stress wave to travel through the wood between the two probes is measured.

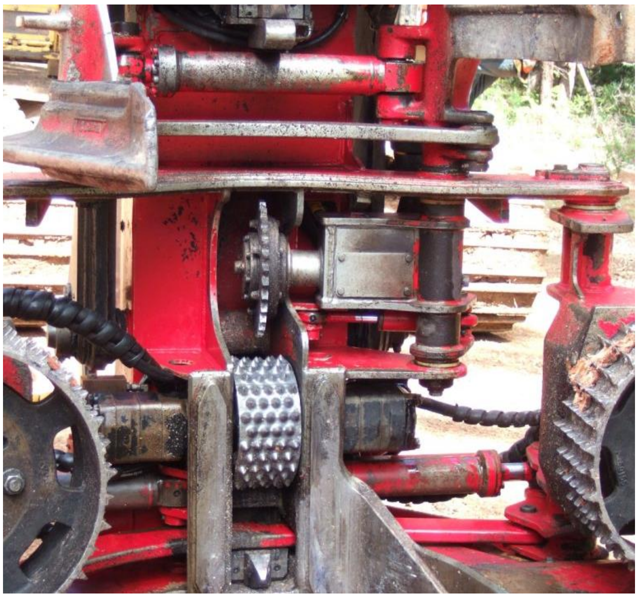

Figure 1. Warratah harvester head with the PH-330 probes highlighted

Previous productivity studies have shown that the PH-300 tool can make an acoustic velocity measurement on a tree in approximately 1.5 seconds, which has a negligible effect on the productivity of a mechanised harvesting operation.

In-Forest Segregation of Veneer Logs

A log-to-product study was undertaken at the Nelson Pine Industries LVL mill to determine the efficacy of the PH-330 tool for segregating out low stiffness logs that are unsuitable for veneer production. In this study, a sample of 119 logs was obtained from 40 trees that were harvested in a 34-year-old radiata pine stand. Three logs were cut from each tree, except for one tree which only yielded two logs. Most logs were 5.5 m in length except for eight logs which were cut to 2.7 m in length. The small end diameter (SED) and large end diameter (LED) of each log was measured over what bark was remaining (generally very little bark was left on the logs). The log position (e.g. log 1, log 2, log 3) within each stem was also recorded and the acoustic velocity was measured on each log using the HM200 (Table 1). The logs were processed into veneer sheets with each individual veneer sheet linked back to a log. All veneer sheets were graded and a dynamic modulus of elasticity (MoE) estimated for each sheet. For each log in the study, the average MoE of all the veneer sheets produced from it was calculated.

Table 1. Summary of the data measured on 119 logs from 40 trees.

Property	Mean value
PH330 velocity (km s^{-1})	4.264
HM200 velocity (km s^{-1})	3.236
LED (mm)	456
SED (mm)	394
Corewood content (%)	36
Heartwood content (%)	26
Taper (mm m^{-1})	11.3

The efficacy of acoustic tools for segregating trees and logs has often been assessed on the basis of the correlation between acoustic velocity and end product modulus of elasticity. However, users of these tools really want to know if they will correctly classify logs, i.e. whether a log passes a certain threshold or fall below this threshold. For example, logs can be classified on the basis of the average modulus of elasticity of veneer sheets that they will produce. There are then four possible outcomes from a binary classifier. If the outcome from the prediction is *pass* and the actual value is also *pass*, then it is called a true positive (TP); however if the actual value is *fail* then it is said to be a false positive (FP). Conversely, a true negative (TN) has occurred when both the prediction outcome and the actual value are *fail*, and false negative (FN) is when the prediction outcome is *fail* while the actual value is *pass.* The aim of any classification scheme is to minimise the false positive and false negative rates. False positives and false negatives have different costs associated with them – too many false positives and the stiffness of the final LVL products will be lower than expected, while too many false negatives means that acceptable logs are being rejected which incurs a lost opportunity.

Using the data from the mill study we developed a number of different models to segregate logs on the basis of the predicted stiffness of veneers that they would produce. To illustrate this concept, we assumed that a log was deemed acceptable if its average veneer stiffness was greater than 9.246 kN mm^{-2}. This value was based on the relationship between HM-200 velocity and veneer stiffness assuming an HM-200 velocity of 3.1 km s^{-1} (i.e. the mill suggested cut-off). Any threshold value could be chosen as the intent here is to illustrate and apply the concepts to the different segregation tools.

The models described in the section above give a probability that a log would meet the threshold veneer stiffness value. To actually assign a log to a class (i.e. pass or fail) a cut-off value for this probability must be used. For example if a cut-off value of 0.8 is used then any logs where this probability is greater than or equal to 0.8 are classified as passing the stiffness threshold.

Receiver operating characteristic (ROC) curves enable the performance of predictive models to be assessed under different probability cut offs by plotting the TP rate (TPR) against the FP rate (FPR). The closer a point is to the upper left corner of the ROC diagram (Figure 2) the closer it is to perfect classification.

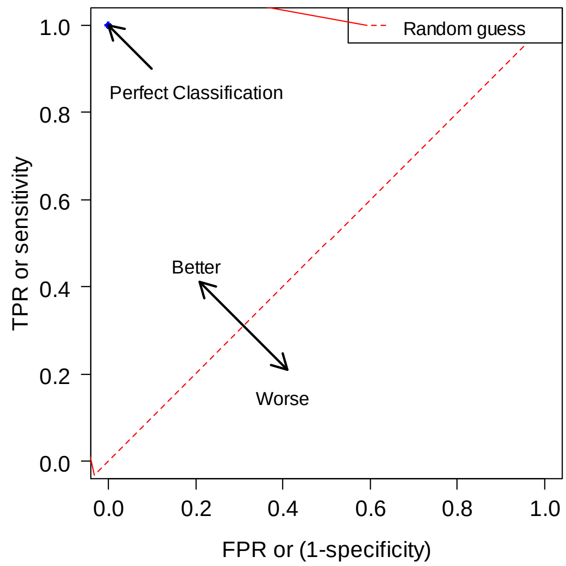

Figure 2. Receiver operating characteristic (ROC) space. The red dashed line indicates classification based on a random guess. Points or curves that sit above this line indicate that classification is better than random.

The ROC curves for the two different acoustic tools show that while the HM-200 tool gets closer to perfect classification compared with the PH330 (Figure 3), this time-of-flight tool can still be relatively effective.

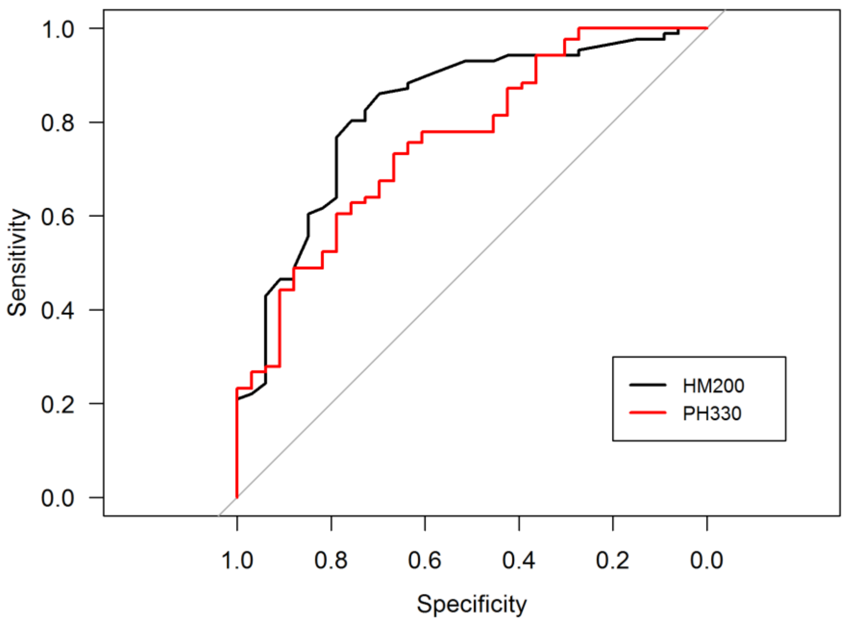

Figure 3. ROC curves for the comparing the performance of the HM-200 and PH-330 acoustic tools. The PH330 tools also segregate logs based on their diameter.

For illustrative purposes, we selected the cut-point for each model that minimised the distance between the curve and the upper left corner of the ROC curve (i.e. perfect prediction). Logs were then segregated based on the models with this cut-point applied and the average veneer stiffness values for the two log populations were compared. These comparisons focussed on the false positive and false negative rates as well as the difference in dynamic MOE of the two populations (lift).

If the logs were segregated based on a threshold value of average dynamic MOE of the veneer sheets, then 86 logs would be above the threshold and 33 below (Table 2). The difference in mean dynamic MOE of the logs in the two groups is 1.75 kN mm^{-2}. The HM200 tool did not incorrectly downgrade any logs, but incorrectly classified 8 logs as passing, when in fact they did not exceed the threshold. In fact, the false positive rate was similar for all approaches, but the PH330 tool (incorporating log geometry) had a higher rate of false negatives (i.e. logs that were wrongly downgraded) than the HM200 tool.

The final analysis was to compare the number of logs rejected by the HM200 and PH330 tools for different criteria related to batches of logs rather than individual logs. The first criterion was that no logs should have a HM200 velocity below 3.1 km/s. When this criterion was applied, 88 of the 119 logs passed with the resulting average veneer stiffness for these logs of 10.159 kN mm^{-2} (Table 3). To achieve the same veneer stiffness using the PH330 tool (in combination with log diameter), 52 logs had to be rejected which gave a reject rate of 43.7% (c.f. 26.0% for the HM200 tool). When the criteria was relaxed so that only 90% of the logs had to have a HM200 velocity of 3.1 km/s, the log average stiffness of the resulting veneer sheets was reduced to 10.091 kN mm^{-2} (8 logs were allowed to have an HM200 velocity of less than 3.1 km/s). To achieve the same target stiffness using the PH330 tool, 37.0% of logs had to be rejected, c.f. 19.3% of logs with the HM200 tool.

Table 2. Comparison of the results from the application of the log segregation models with cut-point values selected to minimise the difference from the upper left-hand corner of the ROC curve.

Segregation method	Number of logs passing	Number of logs failing	MOE dyn passing logs (kN mm^{-2})	MOE dyn failing logs (kN mm^{-2})	False positives	False negatives
MOEdyn	86	33	10.31	8.56	-	-
HM200	77	42	10.26	9.01	8	0
PH330	73	46	10.09	9.39	11	24
Log size	62	57	10.26	9.35	9	33

Table 3. Results from applying different segregation techniques to batches of logs.

Segregation method	Criteria	Mean veneer stiffness	Number of logs passing	Number of logs rejected	Reject rate (%)	Pass rate (%)	Yield reduction vs HM (%)
HM200	HM200>3.1	10.159	88	31	26.0	74.0	-
PH330	HM200>3.1	10.159	67	52	43.7	56.3	17.7
HM200	90% of logs with HM200>3.1	10.091	96	23	19.3	80.7	-
PH330	90% of logs with HM200>3.1	10.091	75	44	37.0	63.0	17.7

Discussion and Conclusions

This study showed that an index based on a PH300 measurement in combination with log diameter could be used to segregate logs for veneer stiffness.

Current segregation practices using the HM200 are not practical to apply in mid stiffness forest stands due to a combination of safety, economic and operational considerations, which mean that only those stands with a high predicted stiffness can be cut for veneer logs without additional segregation, while stands with lower values of predicted stiffness are sold for other uses. Results from this trial showed that segregation using this single threshold automatable harvester head technology could deliver a batch of logs to the mill with the same average veneer stiffness as a batch delivered under a specification that 90% of logs need to have a manually tested HM200 value greater than 3.1 km s^{-1}. While the automated on-head approach would result in a 17% reduction in veneer log yield compared against segregation at the mill using the HM200 tool, such HM200-based segregation would incur substantial costs associated with logs that are cut and delivered to an LVL mill, but are subsequently downgraded because they are not stiff enough.

Results from this trial showed that segregation using the PH330 tool on a harvester head could deliver a batch of logs to the mill that had the same average veneer stiffness as a batch delivered under a specification that 90% of logs need to have an HM200 value greater than 3.1 km s^{-1}. Compared to the base case of no segregation, the automated harvester-head approach delivered a yield of 63% of veneer logs from the sample stand which had an average HM200 velocity of 3.24 km s^{-1}. This would enable substantial extra volumes of veneer grade logs to be extracted from the current resource of mid stiffness stands through in-forest segregation. Analysis of this dataset also showed that segregation of stems at the time of harvest is possible using the log shape and position data (i.e. diameter and log height) obtained from a harvesting head. This indicates that there is scope to modify the software on an existing processor head to be able to segregate logs based on their diameter and position within the stem. Such an approach could result in lower costs to the grower to undertake the segregation as only a software change would be required compared with the PH330 acoustic velocity measure where hardware is also needed. Additional studies are required however to determine the range of stands that this approach could be applied to and what modifications may be required to enable it be applied more broadly. In the interim, it is recommended that a dimension-based approach is only applied to mature stands similar to the trial stand with a predicted HM200 velocity of greater than 3.24 km s^{-1}.

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