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Field application of processor head acoustic technology in forest harvest operations

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Abstract

Recent research and development on acoustic technologies has brought the operational assessment of acoustic speed as a measure of stiffness into forest management and log and lumber processing sectors of the industry. Significant values are associated with stiffness in log supply for LVL veneer production as well as structural lumber manufacture. Measurement of acoustic speed allows this value to be captured through better decision-making, allocation of resource to highest value users, and application of best processing methods dependent upon log-by-log measures. This paper reviews recent experience with field application of acoustic technologies to measure the stiffness of logs and trees during harvesting and log-making operations and discusses research challenges which have arisen. It presents results from in-forest and resulting in-mill log-by-log acoustic measurement and associated values.

Key words: Acoustic technology, forest, logs, processor head, mechanised, nondestructive evaluation, stiffness, trees, wood quality

Introduction

Acoustic velocity through wood can be measured using resonance or time-of-flight based equipment. Research has shown both methods to be useful in predicting the stiffness or modulus of elasticity (MOE) of wood and wood products derived from measured logs or tree stems (Wang et al. 2007).

Recent research and development on acoustic technologies has brought the operational assessment of acoustic velocity as a measure of stiffness into forest management and log and lumber processing sectors of the forest and wood processing industry. Fibre-gen has developed a Hitman® (patented) processor head mounted acoustic measurement system and previously reported research and development has involved the integration of Hitman PH330 mechanised acoustic measurement devices into a Ponsse processor head in UK, two Waratah 626 processor heads in New Zealand, and one Waratah 624 processor head in Oregon US. The system measures the time-of-flight of a sound wave in the stem section held by the harvesting processor head, immediately following the previous cross-cut. Depending on the acoustic velocity value, the operator may cut a different log product from the next section of stem, or segregate the next log, based on a user-defined velocity threshold level.

Significant values can be associated with stiffness in log supply for LVL veneer production as well as structural lumber manufacture. Measurement of acoustic velocity allows this value to be captured through better decision-making, allocation of resource to highest value users, and application of best processing methods dependent upon log-by-log measures.

Measurement of acoustic speed on harvest processor heads has been recognised as a means to enable cutting to the correct log lengths and segregating logs for higher value structural markets. This avoids the need to test after logs are cut to length and having to subsequently re-cut those logs which fail to meet the log buyer's acoustic speed specification. Costs can be significant of re-cutting logs to a shorter length expending resources and generating more waste, with the alternative of selling non-structural logs at a discount in non-preferred lengths.

Two alternative objectives have been highlighted by potential users of mechanised acoustic testing on processor heads; increase the average stiffness of a segregated log batch, or meet some specific Hitman HM200 defined minimum log velocity specification. Different approaches may be necessary to meet these two differing objectives.

Previous results from this work have been summarised and presented at a number of meetings including the presentation in September 2011 at the 17th NDT Symposium in Sopron, Hungary. Development and validation undertaken since the 2011 Sopron meeting has involved retro-fit installation into each of a Waratah 624 in West Australia, and a Waratah 626 in Nelson, New Zealand. These two subsequent validation projects have brought together all of the learnings from the previous projects incorporating a number of features bringing improved performance, precision of acoustic measures, and reliability of mechanical and control systems.

The objective of the West Australia project was to validate the segregation capability of Hitman PH330 to generate a higher average sawmill structural lumber grade out-turn and avoid processing lower stiffness logs into structural product.

The objective of the Nelson project was to validate the segregation capability of Hitman PH330 to meet defined Hitman HM200 specifications required by an LVL veneer manufacturing facility.

Performance Validation

West Australia project

The West Australia project involved retro-fit installation of a Hitman PH330 into a Waratah 624 processor head. This Hitman unit incorporated a similar set of improvements which had previously been made and tested on the Waratah 624 project in Oregon, USA. Project results have been reported (Walsh, D 2012) and involved four phases: 1) installation and calibration; 2) productivity study; 3) log-making and segregation in a 34-year-old radiata pine harvest operation; and 4) a mill trial sawing and grading the segregated log batches.

Calibration

Calibration involved precision testing of 25 successive test cycles with the Hitman PH330 in the same position on one log to be compared against 25 successive hit sets in the same probe holes using the hand operated Hitman ST300. Each hit set involves initiation of eight successive hits, the time-of-flight being

ranked from highest to lowest, and the middle four or tightest clustered set of four recordings being averaged to derive and output a mean time-of-flight and acoustic velocity for the set.

Following this initial calibration, further testing was carried out using the Hitman PH330 to measure acoustic velocity on 168 sawlogs from the selected stand. The results were compared with acoustic velocity measurements taken on the same sawlogs using two hand-held acoustic measurement devices, the Hitman ST300 and Hitman HM200.

Productivity study

The productivity trial was conducted in a 34-year-old radiata pine plantation, with uniform stand and site conditions, after three thinnings. Two 100-tree plots (~0.7 ha each) were established within the harvest site. Every tree within the two plots was measured for diameter and height and numbered for identification during harvesting. Both plots were harvested using a Tigercat H860C, fitted with a Waratah HTH624 C super head and a PH330 installed.

The first plot (the control plot) was harvested without using the PH330 while the second plot (the PH330 plot) did use the acoustic assessment system.For ease of identification, in the PH330 plot, sections of stem with acoustic velocity readings above the selected lower quartile threshold level (‘structural’ sawlogs) were cut into 6.1m or 5.5m sawlogs, while sections of stem with acoustic velocity readings below the threshold level (‘non-structural’ sawlogs) were cut into 4.9m sawlogs. A detailed time and motion study was completed during the harvesting phase for each plot, and a record taken of the products and volumes cut.

Mill trial

Following the productivity trial, the harvester continued to cut and segregate logs from the PH330 plot using the PH330. The intention was to harvest at least 500 m^3 of sawlogs, classified as structural and ‘non-structural’, for the mill trial.

At the mill, the sawlogs were segregated in their respective assortments (‘structural’ 6.1-m or 5.5-m, and ‘non-structural’ 4.9-m sawlogs). Each assortment was then sawn separately into 100 mm × 38 mm green boards. Following milling, the boards were further segregated into four separate batches, based on their original sawlog acoustic velocity assortment and heart status for drying, i.e. ‘free-of-heart’ (FOH) or ‘heart-in’ (HI). FOH and HI boards were separated as a part of the routine sawmill production process using a gamma ray based lumber density sorter which enables separation of heartwood boards from sapwood boards based on their green density.

These batches were then kiln dried and processed through the dry mill where each 90 mm × 35 mm timber board was machine stress-graded.

Nelson, New Zealand project

The Nelson project involved retro-fit installation of a Hitman PH330 into a Waratah 626 processor head. This Hitman unit was redesigned to incorporate the previous 624 improvements with adjustments to suit the different dimensions of the 626 head, along with some further enhancements. A paint marking system was also installed to enable easy identification of logs above and below the acoustic velocity threshold. The study carried out in 2013 involved two phases; installation and calibration, and log-making and segregation in two separate 28-year-old radiata pine harvest operations.

Calibration

Calibration was carried out using the same procedure as outline above for the West Australia project.

Log-making and segregation

Subsequent to calibration, and during the routine harvest and log-making operation, a series of successive log sets were directed to one side of the skid site for further evaluation. Log sets were selected at regular times during the day when it could be accommodated in the production schedule, each comprising 15 - 25 logs in sequence. For each of a total 271 logs, log position within stem, Hitman PH330, and Hitman HM200 acoustic velocities were recorded.

The machine up-time as a proportion of total time available was recorded for a period of 20 operational days. Up-time was considered to be that time when each of the Waratah 626 and the Hitman PH330 were operational without lost time caused by mechanical or other cause of break down.

Results

Calibration and segregation

A series of three independent precision checks from the Hitman PH330 unit installed in West Australia in three separate log positions showed standard deviations of 2.6, 2.6, and 2.7 microseconds respectively on average time-of-flights of 323, 331, and 329. Greater precision was observed in the subsequent Nelson installation (Figure 1) which showed a standard deviation of 1.5 microseconds on an average time-of-flight of 377. Five subsequent precision checks of the Nelson installation showed standard deviations of a 25-test series of the Hitman PH330 time-of-flight of 1.3, 1.0, 1.3, 1.3, and 0.7 microseconds respectively. This compares favorably against the precision of the Hitman ST300 hand tool which showed a standard deviation of 4.5 microseconds for a 25-test series in the same probe holes.

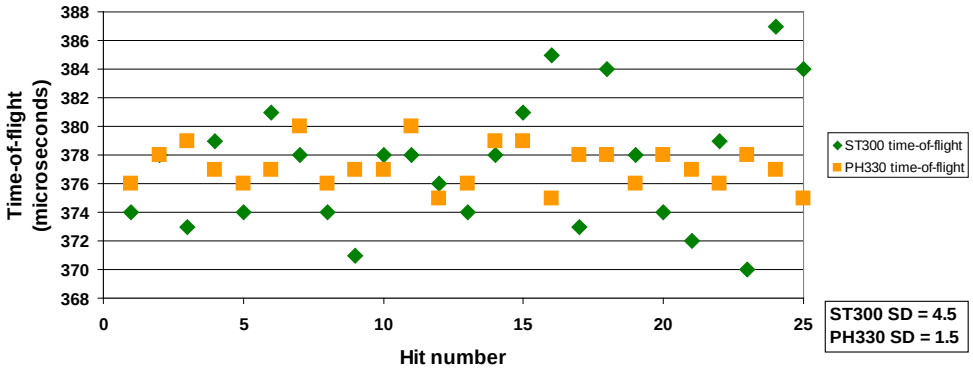

Figure 1—Plot of time-of-flight data showing the relative precision of a 25-test series using the Hitman ST300 and Hitman PH330 devices (Note: standard deviation of the Hitman PH330 is significantly lower than that of the ST300).

Individual Hitman PH330 and HM200 log measurements were taken on 168 logs during the West Australia study. Correlation between individuals showed an r^2 of 0.0.54 and were distributed as shown in Figure 2. Using Hitman PH330 velocity as the basis for log segregation resulted in the selection of the same 5 out of 6 logs which would have been selected if HM200 velocity had been used.

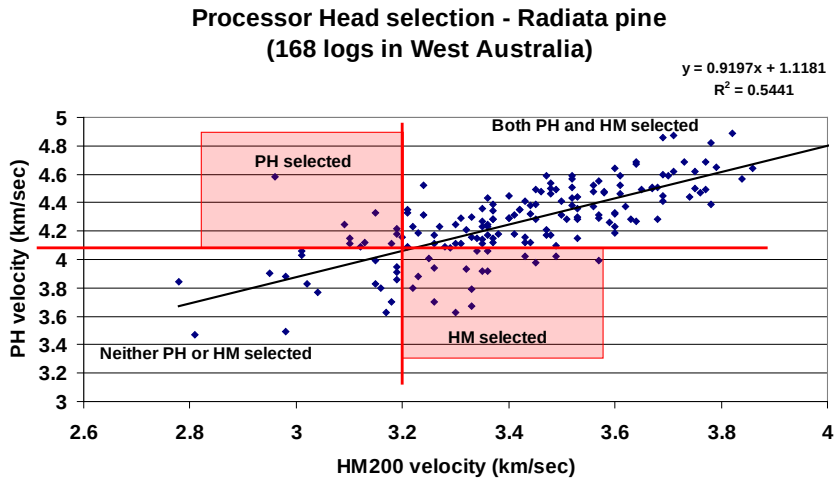

Figure 2—Correlation between Hitman PH330 and HM200 velocity measures on 168 radiata pine logs, highlighting the slightly different selections made using the alternative tools.

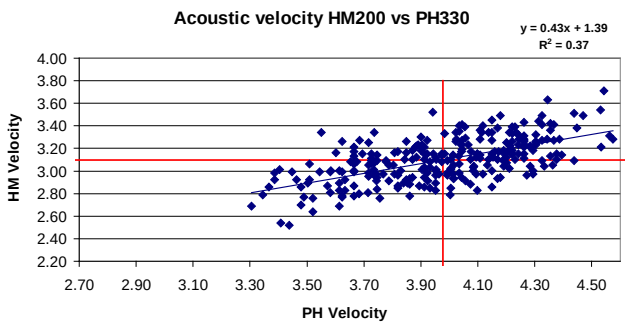

Figure 3—Correlation between Hitman PH330 and HM200 velocity measures on 271 logs in Nelson.

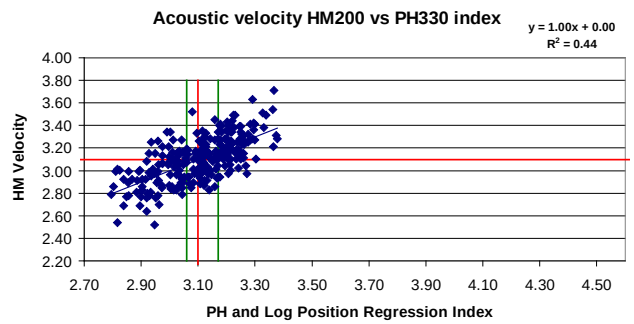

Figure 4—Correlation between Hitman PH330 velocity index including log position and HM200 velocity on 271 logs in Nelson, highlighting the improvement in r^2 using the velocity index.

Individual Hitman PH330 and HM200 log measurements were also taken on 271 logs during the Nelson study. Correlation between individuals showed a lower r^2 of 0.37 as shown in Figure 3. When a PH330 index was generated using a regression including both acoustic velocity and log position within the stem and the index correlated against HM200 velocity, the r^2 improved to 0.44 as shown in Figure 4.

Productivity study

The time study carried out in the two 0.7ha plots with ~100 trees in each as a part of the West Australia project showed no measurable reduction on productivity when using the Hitman PH330. However observation of the PH330 testing process showed a recorded actual average time taken of 1.56 seconds per PH330 test so a theoretical approach was taken to derive a potential productivity impact. At mean 'normal' tree size (1.95m^3) a model based estimated of the impact of operating the Hitman PH330 indicated a 4.2% decrease in productivity (not statistically significant) when using the PH330.

While productivity impact was also considered as a part of the Nelson project, it was a cable hauler operation where production is ~250m^3 per day, constrained by piece size and haul distance. The Waratah

626 processor has a production capacity in excess of 500m^3 per day so operation of the Hitman PH330 had no impact on crew daily productivity.

Hitman PH330 reliability was monitored in the Nelson project during the validation period and over the 20 day period PH330 uptime exceeded 94%. During this same period Waratah uptime was 92% indicating the Hitman PH330 was at least as reliable as the processor head on which it was installed.

Mill study

Structural out-turn from the four batches of boards in the West Australia mill trial are presented in Table 1. Both the Hitman PH330 segregated 'structural' logs and 'non-structural' logs (those from logs tested above and below the lower quartile threshold respectively) generated high levels of structural board recovery from the outer-wood (FOH; free-of-heart) showing little difference in the structural grade recoveries between the two batches of boards.

There was however a significant difference between the structural grade out-turn of the two batches of corewood (HI; heart-in) boards. Sawlogs with Hitman PH330 acoustic velocities above the selected threshold (‘structural’ sawlogs), had a much higher recovery of HI structural grade boards than those below the selected threshold. A statistical comparison of the mean of the average MOE readings for each board produced in each of the four batches showed they were significantly different ($\alpha = 0.05$).

A cost-benefit analysis indicated that the HI timber boards sawn from the low stiffness (‘non-structural’) sawlogs identified by the Hitman PH330 would be better sold as green off saw (GOS) product in most market conditions, rather than incurring the extra cost of kiln drying and further processing.

Table 1—Structural grade recovery for the four batches of boards.

	Structural FOH	Non-structural FOH	Structural HI	Non-structural HI
Structural Grade Recovery	91.8%	88.4%	70.7%	56.4%

Table 2—Example potential benefits from using Hitman PH330 to segregate structural logs from within non-structural stands in two regions of New Zealand.

Region	Hitman ST300 mean velocity (km/s)	Hitman HM200 mean velocity (km/s)	Proportion of logs >3.1 km/s	Benefit/crew day
Nelson, NZ	4.25	3.10	50%	$1,775
Northland, NZ	4.43	3.23	72%	$2,574

Table 3—Cost and sensitivity analysis for using Hitman HM200 and PH330 to segregate structural logs from within non-structural stands.

Log segregation	Cost summary [a]		Sensitivity – Hitman PH330 cost/m^3		
	Crew cost/day	Cost/m^3	Sawlog production/day	200 m^3/day	400 m^3/day
Do nothing	$1,500 - $3,000	$15.00	20% Structural	$4.42	$2.21
Hitman HM200	$300 - $1,300	$1.50 - $6.50	35% Structural	$2.53	$1.26
Hitman PH330	$185 - $260	$0.88 - $4.42	50% Structural	$1.77	$0.88

[a] Costs comprise labour associated with using the Hitman HM200 tool; loader to sort the logs marked as structural or non-structural on the skid site; labour and chainsaw to re-cut non-structural logs to a shorter length; wood wasted as non-structural logs are shortened to the next lower value market length; and in the case of PH330, equipment lease and servicing costs

In the Nelson project there was no associated mill study because prior experience and trial results had shown the Hitman HM200 log velocities were effective predictors of subsequent mill out-turn.

Potential financial benefits have been derived for the projects outlined above along with other situations where Hitman PH330 could be applied. Examples of the benefit of operationally extracting structural logs from within what would otherwise be considered non-structural stands are summarised in Table 2 and Table 3.

Conclusions and discussion

Calibration results show the Hitman PH330 to be more precise than the hand-held Hitman ST300 tool. This could be expected due to the more consistent amplitude of hit from the mechanised initiation of the 8 successive hits by the PH300 while the ST300 relies upon the somewhat variable amplitude and angle of hit generated by manual hammer hitting. Further precision improvements of Hitman PH330 velocities relative to those generated using the ST300 could result from the lack of any distance variability in the PH330 vs that of the ST300.

While it is noted that the precision of the Hitman PH330 was higher in the Nelson installation than in West Australia, the correlation of PH330 velocity vs HM200 velocity was lower in Nelson. This cannot be explained by the differing sample size as the Nelson sample was larger than that in West Australia, but the explanation probably lies in the variability of the Nelson log resource having been grown on the side of relatively steep slopes with the presence of lean and resulting compression wood quite common. Because the PH330 uses a time-of-flight velocity measure, and the HM200 uses a resonance-based measure, compression wood on one side and near the base of the stem will have a greater impact on the measured velocity from the PH330 than that from the HM200 tool.

Segregation in the West Australia project resulted in the selection of five out of six sawlogs being the same using both PH330 and HM200 tools. In this case the segregation threshold split the log population at around 80% above and 20% below threshold. In contrast the Nelson project was targeting segregation of a structural log batch comprising close to 50% of the otherwise suitable log population, and the additional client requirements of no more than 10% of logs in the selected structural log batch being below a specified HM200 velocity, and no more than 20% of the available structural logs being mixed in the non-structural batch.

While this rigorous level of selection may have been able to be met in higher average velocity Nelson stands where about 80% of logs were above threshold, in lower velocity stands where about 50% of logs were above threshold it was not possible. This is due to the imperfect relationship between PH330 and HM200 velocities, and the rigorous client requirements specified. The addition of log order with acoustic velocity into an index improved the power of segregation, but still not to the level required.

Using the results from the Nelson project an alternative strategy of deployment was developed involving the use of two threshold levels rather than one. Using a single threshold logs are either included in the structural log batch or not depending upon whether they have a velocity or velocity-based index above or below the threshold. A two threshold strategy includes all logs above the upper threshold in the structural batch, all logs below the lower threshold in the non-structural batch, and those between the thresholds being further tested with the HM200 tool and split above or below based upon the HM200 specification. It was found that typically a mid band comprising 20% - 40% of the log population enables the defined HM200-based specification to be met in the Nelson case.

In the West Australia project where the processor head was typically on the critical path for daily crew productivity, an intense productivity study was carried out. It is interesting to note that the intensive time study was unable to measure any loss of productivity when using the Hitman PH330. This result serves to illustrate that using the PH330 acoustic assessment system results in only a small productivity impact on the harvesting phase, and that there are other factors which were unable to be identified and measured which impacted the processor head's productivity more than the use of the Hitman PH330.

Any potential small impact of using the Hitman PH330 may be further mitigated by testing acoustic velocity while other operations are being carried out such as during the felling operation or while slewing the stem during processing. Further by application of a simple set of testing guidelines the need for testing all logs could be reduced such that only a subset of logs need be tested eg if the first two logs have a high velocity it can be assumed for operational purposes that the third log will also be high.

Mill trial results from the West Australia study demonstrated that the Hitman PH330 was able to identify lower stiffness sawlogs in the forest before any mill processing was undertaken. A cost-benefit analysis suggested the sawmill would gain financially by directing HI (corewood) boards sawn from these sawlogs to GOS (green sawn) product, rather than paying the additional processing cost for drying, planing, and grading them while suffering 43.6% failure rate of the resulting boards.

An example-based analysis of benefits and costs showed positive net benefit from the potential use of Hitman PH330 to segregate structural logs from within stands otherwise considered non-structural in Nelson and Northland Regions in New Zealand. In markets where there is a log sale price premium of $15/m^3, benefits of segregating structural logs from within non-structural stands can range $1,500 - $3,000 per harvest crew day. Segregating these structural logs using the hand held Hitman HM200 tool as an alternative to the Hitman PH330 can only be done following log making, so suffering both the cost of the manual HM200 operation as well as the cost and waste of re-cutting those logs found to be non-structural to shorter client specified lengths.

Hitman PH330 technology has now been demonstrated through a series of research, development, and validation projects over a period of six years and has been confirmed capable of delivering effective segregation strategies to reliably meet a range of market and end user requirements.

Acknowledgements

Developing and introducing new technologies to the sector is a huge task. Many parties have been involved, too many to name individuals, but they have so willingly made significant contributions of their time, ideas, and financial support without which this work could not have been carried out. This huge contribution is gratefully acknowledged.

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Abstract

The 18th International Nondestructive Testing and Evaluation of Wood Symposium was hosted by the USDA Forest Service's Forest Products Laboratory (FPL) in Madison, Wisconsin, on September 24–27, 2013. This Symposium was a forum for those involved in nondestructive testing and evaluation (NDT/NDE) of wood and brought together many NDT/NDE users, suppliers, international researchers, representatives from various government agencies, and other groups to share research results, products, and technology for evaluating a wide range of wood products, including standing trees, logs, lumber, and wood structures. Networking among participants encouraged international collaborative efforts and fostered the implementation of NDT/NDE technologies around the world. The technical content of the 18th Symposium is captured in this proceedings.

Keywords: International Nondestructive Testing and Evaluation of Wood Symposium, nondestructive testing, nondestructive evaluation, wood, wood products

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