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Summary
Internal scanning investigations of slash pine short-length log samples were undertaken by measurement providers in Australia, New Zealand and the USA. The primary aim of these investigations was to ascertain the capability of currently available internal scanning techniques to rapidly delineate the extent and severity of resin streak and resin shake defects in green debarked logs. The scanning techniques tested were x-ray digital radiography, x-ray helical computed tomography, low intensity microwave reflection and radio frequency scanning.

A summary of the key outcomes of each scanning investigation is provided. Only two of the scanning techniques appear to be potentially viable, namely, X-ray helical computed tomography and low power microwave reflection. However, the microwave investigation undertaken was essentially a feasibility study, so further investigation is required to clearly determine the practicality of the technique within a real log scanning environment.

X-ray CT is a mature technology with capabilities that are probably now able to match the performance demands of the timber industry. It certainly remains the only proven internal log scanning technology. However, issues related to capital cost, costs associated with systems integration, in-service availability and, most importantly, the formation of a joint venture between an equipment manufacturer and a motivated timber company or a consortium of interest, are problematic.

Internal log scanning is unlikely to attract manufacturing interest to produce commercial prototypes unless a whole of forest industry business case is developed and supported.

Introduction

Internal scanning investigations of slash pine short-length log samples were undertaken by measurement providers in Australia, New Zealand and the USA. The aim of these investigations was to ascertain the capability of currently available internal scanning techniques to rapidly delineate the extent and severity of resin streak and shake defects in green debarked logs. A secondary objective was to also ascertain their capability to detect knot position and size.

The scanning techniques tested were x-ray digital radiography, x-ray helical computed tomography, low intensity microwave reflection and radio frequency scanning. A summary of the measurement providers and their scanning techniques compared in this project is given below.
This research project was funded by the Forestry and Wood Products Research and Development Corporation (FWPRDC) with project in-kind contributions from Weyerhaeuser Australia, Department of Primary Industries and Fisheries (DPI&F), Keam Holdem Associates, DPI Forestry, Hyne and Son, Mississippi State University and Boral Limited.

The key outcomes of the scanning investigation are discussed along with suggested further work, including a recommended test approach for the conduct of any future internal log scanning tests to detect resin defects, and a discussion of the need for a business case and consortium of interest to evaluate whether internal log scanning can become a commercial reality in Australasia.

**Test samples**

Sets of green log samples were collected as short log sections about 850mm long. The samples were docked from logs in the Weyerhaeuser Australia log yard at Caboolture and were sourced from south east Queensland; either from Toolara State Forest, Caloundra Downs or Beerburrum State Forest. Comparable sets of material of very similar size and resin defect occurrence/severity were selected. This required surveying log stacks and identifying likely sample logs displaying resin defect of mild, medium and severe extent. Each set of logs assembled for testing by each measurement provider contained a sample of each resin class and contained at least one prominent knot whorl (3 – 4 knots). An additional severe class sample was sent to Dr John Davis to allow this sample to be validated by longitudinal sawing of the log. This allowed a comparison of this method of validation of scanning results versus the cross-sectional dissection used for all other samples and it successfully highlighted some features that were not clear in the cross-sectional discs.

All bark was removed from the log samples and they were clearly identified with uniquely numbered log tags. The log samples were plastic wrapped to prevent drying during transport. They were shipped by air freight so that the time between collection and testing was minimised. Therefore, the samples closely represented the green condition of typical log-yard material, pre-processing. The samples for Dr Davis were transported to Cairns using express road freight.

To meet quarantine phytosanitary requirements the samples for Keam Holdem and Mississippi State University were heat treated in a research kiln, with high relative humidity control to minimise moisture loss, for a minimum of 75 minutes continuously once a minimum core temperature of > 70º C was achieved. Prior to shipment they were inspected by the Australian Quarantine Inspection Service (AQIS) and a Phytosanitary Certificate issued.
Outcomes of the Scanning Investigations
An assessment of the four scanning techniques is provided below.

1. X-ray digital radiography
X-ray digital radiography was rejected as a viable technology for internal detection of resin defects because it was not possible to obtain contrast between the resin defect structures and the surrounding sapwood dominated matrix. The large sapwood band in slash pine occupies approximately 90% or more of the log volume and this characteristic feature also makes it difficult to reveal knot whorls along the stem.

2. X-ray helical computed tomography
Computed tomography (CT) is able to accurately measure the resin defect structure and the knot whorl distribution within slash pine logs. The scanning measurements clearly showed, within the resolution constraints of the scanner, that the presence of resin is always associated with the existence of wood tissue fracture or shake. Some of these fractures are not clearly visible to the naked eye without high magnification or other artificial enhancement. The general morphology of resin defect structure appears to follow the spiral grain habit of the stem.

CT scanning basically sets the benchmark and datum for other non-destructive scanning techniques. The current status of the CT technology suggests that the internal information obtained in this study can be achieved under real industrial conditions. Given the very detailed level of information obtained it would seem that considerable flexibility is available to tailor the sensitivity of the technology to meet industrial productivity requirements.

3. Low power microwave reflection
The results from this test demonstrated the feasibility to detect and estimate the size of shakes or cracks within the log samples. There is good evidence to suggest that the frequency domain analysis technique used can yield reasonably accurate and reliable information about the radial and longitudinal extent of the resin defect structure within a log. This study focussed upon shake/crack and knot detection rather than the detection of resin flooding as a separate feature.

The measurement provider is confident that the precision and validity of their results could be considerably improved and extended to enable a coarse resolution mapping of the longitudinal location of knots and, importantly, the radial and longitudinal distribution of the resin defect structure. However, further investigations are needed to determine whether the technique can provide the necessary internal information when practical parameters such as variable air gaps between source and log, realistic linear log speeds and larger diameter logs are considered. Therefore, considerable further testing work is required to fully evaluate whether this technology can meet the requirements of industrial conditions.

4. Electrical impedance tomography
This is a technique that attempts to produce coarse spatial resolution maps of the distribution of electrical conductivity within a cross-sectional slice of a log. The technique has attracted attention in medical imaging and in the monitoring of complex dynamic fluid flows in
industrial pipeline systems. The measurement providers have expertise in the application of radiofrequency techniques to the scanning of sawn boards and in recent years have extended their scanning interests to the EIT technique known as the Through-Log-Density-Detector (TLDD).

For the purposes of this test the laboratory measurement procedure required that the log be initially shaved to approximate a regular cylinder and a set of eight equidistantly-spaced electrodes were arranged in a circle around the log sample prior to measurements being taken. The technique as it applies to logs has been patented by the measurement provider. However, it does not appear to be compatible with industrial log scanning requirements as we were evaluating in this study.

The EIT results did not suggest that this technique warrants further development since it appears to be essentially a laboratory procedure and did not produce reliable results at significant depths into the log cross-sections. The large sapwood band in slash pine only appeared to have been penetrated by this technique to the depth of the outer 6 – 7 growth rings. Further, it would seem that the measurement methodology cannot meet industrial log scanning requirements since the reliable and valid application of metallic electrodes to the surface of a log is not readily achievable even under laboratory test conditions. It is also well known within the EIT field that large changes in the internal electrical conductivity distribution can result in small and difficult to measure voltage changes.

**Scanning Trial Outcome: Proven and Potentially Viable Methods**

Of the scanning techniques assessed in this investigation, only x-ray CT and microwave reflection remain as proven and potentially viable log scanning methods, respectively.

X-ray CT is a mature technology with capabilities that are probably now able to match the performance demands of the timber industry. It certainly remains the only proven internal log scanning technology. However, issues related to capital cost, costs associated with systems integration, in-service availability and, most importantly, the formation of a joint venture between an equipment manufacturer and a motivated timber company or a consortium of interest are problematic.

Although the microwave results represent a feasibility study, there is sufficient evidence to suggest that a further exhaustive proof-of-concept program may be justified to determine whether the technique could satisfy the following requirements:

- Precisely define the resin structure defect (cracks + resin) consistent with the known distribution as revealed by x-ray CT
- Demonstrate that internal knots can be differentiated from zones of resin streaking/flooding
- Show that the internal distribution of resin defect (and possibly knots) can be longitudinally mapped and be consistent with the results obtained from x-ray CT.
- Demonstrate that certain practicality factors can be satisfied so that internal information can be acceptably determined. The factors will include:
  - Measurement of internal features using variable air gaps between the microwave source and the log surface.
  - Measurement of internal features assuming linear log speeds (past the microwave source) of up to 100 m/min.
The capital costs associated with the introduction of an acceptable commercial microwave log scanning technology are likely to be considerably less than the costs associated with x-ray CT. However, this assumption has yet to be tested and financial modelling involving the adoption of either of these two technologies also has to be undertaken.

**Recommendations for future work**

Microwave reflection technology may be simpler to adopt than x-ray due to the up-front hardware costs and the extra shielding and workplace health and safety infrastructure needed to develop an x-ray based system. The latter complexities also may be more limiting to the adoption of x-ray technology in a road-side harvesting situation versus mill log yard. However, the economic benefits of harvest versus log yard screening/diversion would need to be evaluated.

As indicated above, the trial results for the microwave reflection technology are positive in terms of the initial feasibility of this technique but they need confirmation in a follow-up test that addresses some of the practical issues identified as potentially limiting for commercial adoption. Other technologies, such as radar and resonance, that might be tested for internal log defect detection, should be compared to helical CT scanning as the proven reference technique with the key requirements for a test approach outlined below.

Any follow-up testing should involve CT scanning of test logs to identify 1 or 2 that contain the full suite of features that microwave reflection or any other technology would need to detect with some degree of certainty to substantiate its value for development to a prototype stage. The key features to be tested would include:

- sensitivity to detection of a resin filled crack versus an open crack with an air-filled void - i.e. can microwave reflection distinguish between solid wood and a resin-filled crack
- ability of microwave reflection to detect cracks down to 0.5 mm in width
- ability of microwave reflection to predict the radial width and longitudinal length of any resin shakes (cracks) in a log - i.e. map the extent of a resin crack in a log (there was some indication from the trial that this is possible)
- ability of microwave reflection to consistently separate knots from resin defects (either cracks or resin flooded wood).

Testing would require CT-scanned log reference sample/s to be provided to the measurement provider and their scanning results then compared to the CT data. All tests would need to be undertaken using an air-gap of at least 40mm from the log surface to the sensors and the maximum practicable measurement distance would need to be determined. This test would primarily need to pass the sensitivity/detection tasks in the dot points above while demonstrating an understanding of the impact of throughput speed on the quality of outcomes. For example, for microwave reflection, given that there is an orientation dependence related to the effect of internal structure on microwave polarisation, there is a need to establish how many transducers/measurement positions are required to generate reliable results.

**Where to from here?**

To obtain serious interest from an industrial x-ray manufacturer to develop a timber industry CT scanner the production of a business case that incorporates a much broader forest industry base than the current study of resin defects in pines is required. Potential applications within the Australasian forest products industry may include:
(i) Resin defect detection for log sorting prior to sawing in slash pine and other southern yellow pine logs

(ii) Knotty core definition in veneer and sawn clearwood logs – radiata pine, hoop pine and plantation hardwoods (eg older age NSW E. grandis plantings)

(iii) Defect detection in high pruned butt logs for clearwood products (radiata pine, hoop pine and some hardwoods).

The viability of CT log scanning or internal scanning in general is essentially in the hands of the forest products industry and the relevant technology providers. A case for internal scanning exists when key internal quality and value information cannot be inferred externally as has been demonstrated for resin defects in slash pine. A sawing study undertaken as part of this FWPRDC project confirmed the results of previous sawing studies in slash pine, clearly indicating that there is no reliable correlation between resin defects visible on log ends and their impact on sawn grade recovery and value. Whether the internal information is pursued using sophisticated technology, which this study demonstrates that it must be, will depend on the results of a detailed financial assessment. CT companies manufacture a narrow product line or they construct one-off systems for a wide range of clients. To interest a manufacturer in the development of a log scanner will require a compelling business case to divert attention from core business and will certainly involve a significant investment from the timber industry partner/s. A credible business case would necessarily require the identification of a potentially large application market and a selection of one or a small number of most likely CT technology providers.

**Conclusion**

A test of four internal log scanning technologies has demonstrated that the scanning techniques of x-ray CT and microwave reflection represent proven and potentially viable log scanning methods, respectively.

If the microwave technique is to be explored in exhaustive detail in a proof-of-concept project, this project would ideally be a joint venture between an industry consortium of interested parties and the measurement provider, Keam Holdem Associates Ltd. The outcome of this project is needed to clarify whether this technology can be realistically considered in a business case examining the economic viability of internal log scanning.

Nevertheless, internal log scanning is unlikely to attract interest from technology manufacturers to produce commercial prototypes unless a credible whole of forest industry business case is developed and supported. A credible business case would necessarily require the identification of a potentially large application market and a selection of one or a small number of most likely technology providers.

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The log samples were supplied by Weyerhaeuser Australia, Caboolture and sampled with assistance from Greg Levinge (Weyerhaeuser). Terry Copley (DPI&F) co-ordinated the collection, storage, phytosanitary treatment, quarantine inspection (AQIS) and shipping of all log samples.
The work and collaboration of the technology providers, who completed the scanning work for this milestone, is gratefully acknowledged. Dr John Davis undertook direct X-ray Digital Radiography and X-ray Helical Computed Tomography. Post-scanning, logs for the latter work were sawn at DPI&F’s Salisbury Research Centre by Eric Liette, Martin Davies and Terry Copley. Ms Gloria Vega, Applications Engineer with Keam Holdem Associates Ltd. (New Zealand), used Low Power Microwave Reflectance to scan the samples provided. Follow-up information was provided by Nigel Greig, Research & Marketing Manager, Keam Holdem, who also participated in very useful email and phone conference discussions to improve our understanding of the potential of this technology. Dr Philip Steele supervised a team at Mississippi State University (Jerome Cooper, Adam Harris and Brian Mitchell), which undertook scanning with electrical impedance tomography technology using their patented Through-Log Density Detector.