J. W. GOTTSTEIN MEMORIAL TRUST FUND

The National Educational Trust of the Australian Forest Products Industries

GOTTSTEIN TRUST

TECHNOLOGY FOR DELIVERING HIGH QUALITY GRADED SOFTWOOD PRODUCT – PRACTICAL APPLICATIONS

GREG DUFF

2005 GOTTSTEIN FELLOWSHIP REPORT

JOSEPH WILLIAM GOTTSTEIN MEMORIAL TRUST FUND

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are:

1. Fellowships and Awards - each year applications are invited from eligible candidates to submit a study programme in an area considered of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their programme. These are then distributed to industry if appropriate. Skill Advancement Awards recognise the potential of persons working in the industry to improve their work skills and so advance their career prospects. It takes the form of a monetary grant.

2. Seminars - the information gained by Fellows is often best disseminated by seminars as well as through the written reports.

3. Wood Science Courses - at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.

Further information may be obtained by writing to:
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GREG DUFF

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Greg is relatively new to the Australian forest products industry, beginning his role with Wespine Industries in April 2004.

Greg's background is in mechanical maintenance engineering, with prior technical and key-account management experience with consultancies delivering condition-based maintenance solutions to a wide range of industries – including oil and gas, mining, power generation and manufacturing.

Greg graduated with a Bachelor of Mechanical Engineering from the University of Western Australia in 1997. He has a Graduate Certificate in Maintenance Management from Monash University (Victoria) and Certificate IV level training in Business Marketing with the Australian Institute of Management.

ACKNOWLEDGEMENTS

I would like to sincerely thank the Gottstein Memorial Trust Fund for the opportunity to carry out my Fellowship research. I hope my report and the experience I gained deliver benefits to the Australian forest products industry.

I would like to thank my employer, Wespine Industries, for affording me the time away from work to undertake what was an extensive travel itinerary.

The success of my research relied on the extreme generosity of the various manufacturer contacts that I met, who made time to accommodate my visit and answer all of my questions. Their willingness to share information and facilitate the mill visits was greatly appreciated. I am also grateful to the mill personnel for their time.

I would like to especially thank my wife, Jacalyn for her role as ‘project manager’ and for her patience and assistance in bringing the report together finally.

Thanks also to my parents for their love, support and ‘baby-sitting’ duties.

Finally, thanks to family, friends and peers for taking the time out of their busy lives to review the report and provide invaluable feedback.

EXECUTIVE SUMMARY

The grading process employed for the production of most of Australia's structural pine products is based on mechanical stress grader designs that are at least 30 years old, and it demands visual grading to underpin grade decisions. The production speeds, reliability and data handling capabilities of mechanical stress graders have of course progressed significantly over this time, but it is the author's opinion that there are now alternative technologies that can deliver a more effective grading regime overall.

Eleven commercially available grading machines were investigated that employ alternative technology to the 'traditional' approach. The research was conducted via a combination of manufacturer and mill visits, along with contact at trade shows. Very few of the machines are over 10 years old, with around half being less than 5 years old. The design context for the machines varied, with a number being developed in response to client requests for specific production-related solutions. Other machines have been designed by manufacturers adapting sawmill optimisation technology for planermills.

Different machines focus on different aspects of the overall grading process. Machines that deliver an alternative to mechanical stress graders promote a broad range of benefits including non-contact measurement, simplicity, ease-of-use, reduced space demands and less maintenance. A number of these machines employ multiple grading modulii to improve the strength of relationship with design parameters – this offers exciting potential for grading accuracy and recovery as well as confidence levels for quality control methods.

The machines offering an alternative to visual grading were particularly impressive in their ability to accurately classify a wide range of external characteristics.

Of significant benefit were the improvements in grading accuracy and consistency – leading to better grade recovery and reduced trim loss. Faster production rates are also possible, as are reductions in labour requirements.

Application of the external scanning technologies for processing local radiata resource is not considered a problem, with the majority of manufacturers already processing - or at least trialling - a broad range of softwood species. Manufacturers that employ acoustics for stiffness prediction or non-contact x-ray scanning for strength prediction believe these technologies will also work accurately on radiata. It is felt that specific trials should be completed to better understand the effectiveness of these technologies, given the strength-limiting impact of knots in radiata. In relation to this, it may still be found that there is significant benefit in physically loading (or ‘proof’ stressing) material as per the current grading process – as this identifies true ‘bad actors’.

The most promising technology investigated for identifying ‘rogue’ boards is the tracheid effect sensor. This technology provides a means of quantifying deviations in grain structure. The challenge remains to effectively classify the severity of particular deviations such that a ‘rogue’ characteristic can be graded out.

It is clear that the technology employed in many of the machines investigated is still being optimised, whilst new sensor technology is also being developed. Few manufacturers promote a ‘graderless’ process but this remains their ultimate goal. What is also clear is that there are a significant number of sawmills around the world who are reaping the benefits of these technologies right now. It is believed that the machines investigated offer a broad range of benefits to Australian producers too. The benefits that will be of most significance to a particular producer will depend on their goals and priorities in terms of the grading process.

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1. INTRODUCTION

1.1. Purpose of Research

The introduction of Machine Graded Pine (MGP) into the Australian market in 1995 represented a significant step in the evolution of structural-grade radiata pine production. MGP material is graded in a two-step process that first uses a mechanical stress grading machine to sort the timber on the basis of its Modulus of Elasticity, followed by a visual grading regime designed to confirm the strength and utility-limiting impact of characteristics remaining on each board.

Technological advances in wood profiling, scanning and imaging – both for internal and external characteristics – as well as acoustics have seen new grading machines appear in various markets around the world. The purpose of the following research has been to investigate a number of these commercially available tools to determine the benefits to operators in terms of grading for wood quality, recovery and process efficiency.

With each specific machine, the following points were of primary focus to the research:

- How does the machine work – what technology does it rely upon?
- Under what context was it designed, and what issues relative to grading does it aim to address?
- How successful is the technology in achieving these aims?
- What are the unique value propositions put forward by the manufacturer – how does it differentiate itself?

The research also encompassed visits to mills where specific machines had been installed and were in operation. This provided the opportunity to discuss with operators how the machine works in the context of their grading operation as well as identify key benefits in its application. Critical issues such as interaction with grading agencies and quality control were also addressed.

2. RESEARCH SCOPE

2.1. Scope of Visits

There are numerous manufacturers world-wide producing commercially available tools designed to improve softwood segregation and product grading. The aim of this project was to gain exposure to a range of different machines and technologies. It was also considered important to understand these applications in a number of different markets and grading contexts.

The scope of the research visits can be broken down into two categories – the first being 'full visits' to manufacturer's facilities to discuss all aspects of machine design, followed up with a visit to a mill where this technology can be observed in a production application. The second category was a 'partial' visit (due to time constraints) to either a manufacturer's facility alone, or to a mill where the technology has been implemented, or via brief contact at a trade show.

'Full' visits were achieved with the following manufacturers and associated mills:

NORTH AMERICA

Manufacturer	Machine	Mill Visited
Autolog Montreal, Quebec	Linear Planer Optimiser (LPO) with Visual Defect Detector (VDD)	Claude Forget Inc. Laurentide, Quebec. Bowater Maniwaki, Quebec.
Coe Newnes/McGehee, Portland, OR	D*TEC 5000 BioScan	Stimson Lumber Company Forest Grove, OR

NORTH AMERICA (cont'd)

Manufacturer	Machine	Mill Visited
Coe Newnes/McGehee Salmon Arm, BC	Linear High Grader (LHG)	Western Fraser Mills (WFM) Chasm, BC
Lucidyne Technologies Corvallis, OR	GradeScan (ChopScan & RipScan)	Sierra Pacific Red Bluff, CA

EUROPE

Manufacturer	Machine	Mill Visited
Dynalyse Partille, Sweden	Dynagrade	Derome Timber AB (Derome Sawmill) Varberg, Sweden
Innovativ Vision Linkoping, Sweden	Woodeye Sorter	Stora Enso Ala Sawmill & Kopparfors Sawmill (300km north of) Stockholm, Sweden

'Partial' visits included:

NORTH AMERICA

Manufacturer	Machine	Nature of Visit
Metriguard	Model 7200 High Capacity Lumber Tester (HCLT)	Manufacturer visit – Pullman, Washington State, USA.
Finscan	Boardmaster NT	Mill visit – Durgin & Crowell Lumber Co, New Hampshire, USA. Contact at Seattle Wood Industry Forum

NORTH AMERICA (cont'd)

Manufacturer	Machine	Nature of Visit
VAB Solutions	TMG-16 Transverse MSR Grader	Laboratory visit – CRIQ. Quebec City, Quebec

EUROPE

Manufacturer	Machine	Nature of Visit
Microtec	Goldeneye and ViScan	Contact at Ligna+
LuxScan Technologies	LaserScan, CombiScan, Xscan-Combi	Contact at Ligna+

2.2. <u>Limitations on the Analysis of Technology</u>

It is beyond the scope of this report to deliver a detailed analysis into the specific technologies employed in the grading machines discussed. This report is focused more on the practical application of the technology. The report aims primarily to develop an understanding of the grading parameter (modulus) for each machine first – that is, for the purposes of grading what is actually measured and what properties can be predicted from this measurement?

The logical extension of this question is then to discuss the specific technology employed – but only to the extent of exploring the context of the design and determining the accuracy of the technology in achieving effective grading.

The report has been structured such that machines are introduced and discussed in a logical order according to a classification in terms of grading modulus. It will be shown that, across the machines investigated, there are 4 general classifications of grading modulus.

The 12 systems can be classified into 4 general groups based on the combination of grading modulus used to make grading decisions. The basic sensor technology behind each group is relatively similar, but variances become apparent in processing and classification strategies.

2.3. Limitations on the Stated System Capabilities

It must be stressed that this research represents a 'snapshot' in time relative to the ongoing development of the grading systems discussed. Although many of the systems began development in the 1980's, they are heavily reliant on computer processing power and speed to allow effective data acquisition, analysis and decision making at mill production speeds.

A common theme throughout the study has therefore been that system capabilities are changing at a rate similar to other industries that are benefiting from the contemporary acceleration in PC processing power. These capabilities include increased production line speeds, improved sensor resolution, enhanced characteristic identification and classification.

With this state of 'flux', it is recommended that readers interested in particular system capabilities use the Manufacturer Contact List (Appendix A) to determine up-to-date specifications.

3. SOFTWOOD GRADING IN AUSTRALIA

3.1. Background to Machine Graded Pine

Machine graded pine (MGP) was introduced in the Australian market in 1995. The material is sold as a dressed, solid and seasoned structural product, typically between 70 – 290mm in width and 35mm or 45mm thickness. MGP material represents the current phase in the evolution of the local structural framing market, which during the 1960's was dominated by hardwoods. By the mid 1960's the 'F-grade' system had been formalised that sorted timber into stress grades based on a visual assessment of the impact of characteristics on strength. Standardised in 1973, the F-grade system was derived from the mechanical strength properties of Australian native hardwoods using small clear wood tests. Alongside the hardwood resource, softwoods were being produced but were grouped into the standard F-grades without acknowledgement of the different structural properties of the material (for example – the ratio of stiffness to strength is very different for softwoods and hardwoods).

Two specific developments were critical to the evolution of MGP. The first was the establishment of plantation timbers – predominantly radiata – in a number of Australian states during the 1950's. These plantations now represent the basis of Australia's structural timber supply. The second development occurred in the 1960's and relates to the domestic and international interest in the relationship between softwood stiffness and strength. Anton & Huddleston (1967) described at the time the acknowledgement of Australian researchers in the "marked reduction in the modulus of elasticity brought about by the defects present and the apparent correlation between stiffness and strength" and in "three machines being developed overseas to make use of this correlation". These machines – which are designed specifically to measure stiffness (on flat) are known as 'mechanical stress graders'.

(It should be noted that, since this time it has been acknowledged that the defect itself relates more to strength limitation – hence the need for visual overrides in grading MGP).

It was not long before two local mechanical stress grading machines were commercialised and sold throughout a number of countries (Forestry Commission of NSW held Patent rights to the 'Plessey Computermatic' machine). With more and more machines coming into existence, further research could be completed on this relationship. Anton (1977) reported that "independent studies by various organisations on a wide variety of species confirm the above correlations [stiffness and ultimate strength] which have been estimated to be of the order of 0.7 to 0.8 when expressed by their correlation coefficient", and that "stiffness measured by loading the timber as a plank can be used as a non destructive strength indicator for timber to be loaded as a joist".

As well as representing a promising means of sorting timber, producers could see the benefits of mechanical stress grading in terms of quality control. Bostrom et al (2000) highlighted these sentiments: "machine grading has several advantages compared to traditional visual grading such as better accuracy, more cost effective and possibly for a good internal control".

The commercial opportunities inherent in the softwood plantation timber, and the development of mechanical stress grading machines led to Australian researchers embarking on an in-grade testing program in the late 1980's. In-grade testing relates to the investigation of structural properties in full-size graded timber pieces as opposed to clear wood samples. The outcome of this study was recognition of the benefits of developing an independent suite of design properties for radiata outside the F-grade system. Subsequently – in the early 1990's a more extensive in-grade testing program was completed that provided a reference population for the establishment of the current MGP grades.

3.2. Framework for Production of MGP

3.2.1. Design Properties

The structural performance of MGP material is characterised by an average modulus of elasticity (MoE) and 5^{th} percentile bending strength (MoR – modulus of rupture) of a sample population (random sample, random test location). Associated tensile, compression and shear strengths are also characterised. AS 1720.1 *Timber Structures – Part 1: Design Methods* defines specific design properties for each of the three current MGP grades (refer Table 1). Design properties are based on (but not necessarily equal to) the characteristic properties of the population.

Grade	5^{th}%ile MoR (MPa)	Average MoE (MPa)
MGP10	16	10,000
MGP12	28	12,700
MGP15	41	15,200

Table 1: Excerpt from Table H1 Appendix H (AS 1720.1)

3.2.2. Grading Compliance

To achieve the structural performance requirements above, MGP material is graded in accordance with AS/NZS 1748:1997 *Timber-Stress-graded-Product requirements for mechanically stress-graded timber.* The grading regime is a two stage process that must be enforced on every board:

1. Mechanical stress-grading
    - The standard defines mechanically stress-graded timber as “timber that has been non-destructively tested by mechanical grading equipment and that meets the product specification contained in this Standard”.
    - The Standard notes that the “stress-grading machine sorts the timber on the basis of its modulus of elasticity”.

- It also states that "particular emphasis has been placed on producing a Standard that facilitates rather than retards the development of technology, by specifying structural product performance requirements over other issues".

2. Visual inspection
   - The Standard acknowledges that all mechanically stress-graded timber must be visually inspected for certain characteristics, "that are not necessarily detected during the mechanical grading process". These can be grouped into strength-limiting and utility-limiting characteristics.
   - Strength-limiting characteristics include knots, resin pockets, bark pockets, heart shakes, cross shakes and splits.
   - Utility-limiting characteristics include dimensional tolerance, squareness, knots, wane and want, machine skip, bow/spring/twist and cupping.
   - The visual inspection must pay particular attention to the ends of the timber – where the stress grader cannot assess the MoE.

Timber designated to a particular stress-grade by the stress-grading machine must be downgraded should it fail to satisfy either of the strength or utility-limiting characteristics during visual inspection. In this way the visual grader *underpins* the grading process.

MGP producers have the flexibility to tighten the permissible characteristics set out in AS/NZS 1748. For example, a number of producers define a permissible knot size – or knot area ratio (KAR) not exceeding 50% to ensure they can deliver a reliable product strength-wise. KAR represents the proportion of cross-section of one or more knots to the cross-section of the board.

The ‘knot’ descriptor relates to all knots - tight or loose, sound or unsound, intergrown or not, round or oval, single or clustered, knot holes, cone holes, holes and occluded branch stubs including any associated bark encasement.

MGP material is seasoned, with specified moisture content limits. AS/NZS 1748 also defines marking requirements – with one grade per piece.

3.2.3. <u>Quality Control</u>

AS/NZS 1748 requires that both initial and periodic monitoring of end product properties is carried out. The relevant Australian Standards are:

- AS/NZS 4063 *Timber – Stress-graded – In-grade strength and stiffness evaluation*
- AS/NZS 4490 *Timber – Stress-graded – Procedures for Monitoring Structural Properties*

Further to this, AS1720.1 requires that each mill must implement a continuous monitoring regime as part of a quality assurance program. The specifics of the continuous monitoring may vary from mill to mill, but essentially involve sampling and testing product continuously during production to check strength and stiffness properties.

The Australian softwood industry’s quality assurance program typically defines steps to ensure appropriate grading machine control. These include:

- Accuracy in stiffness measurement along the length of the board at production speed
- Repeatability of measurement
- Consistency and minimisation of machine bias.

It is the responsibility of the producer to ensure compliance with the designated structural design properties – thereby delivering a 'fit-for-purpose' product to market. Each producer maintains quality assurance policies and procedures in line with their own risk management strategy.

3.3. Production of MGP using Existing Grading Technology

3.3.1. Mechanical Stress Grading Technology

Current MGP grading technology uses the mechanical stress grading machine (MSG) to measure an MoE profile ('E' profile) along the length of the board as it passes through the machine linearly. Refer to Section 4.1.2 for specifics of this technology.

Mechanical stress graders - in the Australian context – typically use the parameter of MoE minimum as the grading modulus. For production, each MGP grade is assigned an MoE minimum ('E lowpoint') threshold by which individual pieces of timber are sorted. Thresholds can vary from mill to mill, and by species and product size. They are directly linked to grade recovery and property compliance.

3.3.2. Production Characteristics

The following discussion aims to highlight how the current two-stage grading regime sorts radiata into MGP grades, and what the implications are in terms of variability in grade properties.

Stage 1: Mechanical Stress Grading

An E profile is developed for each board as it passes through the MSG. The board is sorted into grade by assessing the E-lowpoint relative to the E thresholds for each grade. The board is then typically spray-marked before visual grading.

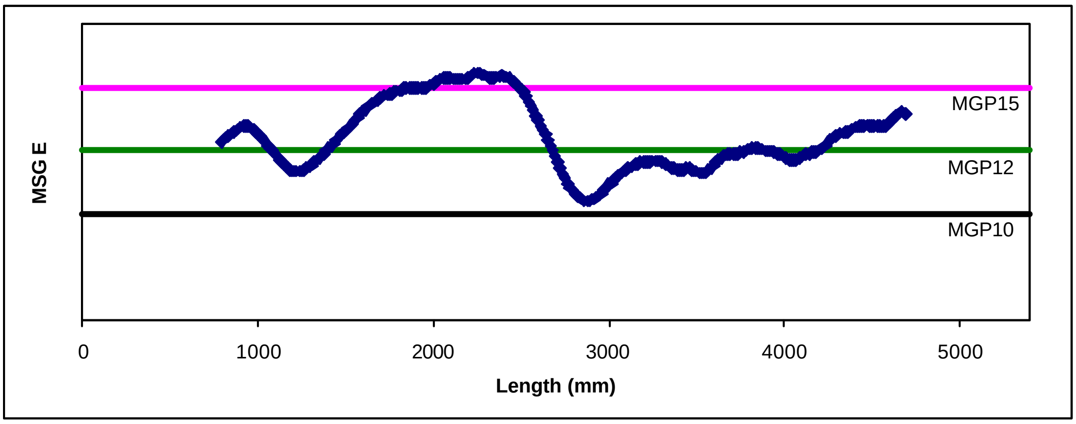


Fig. 1: Typical 'E' profile

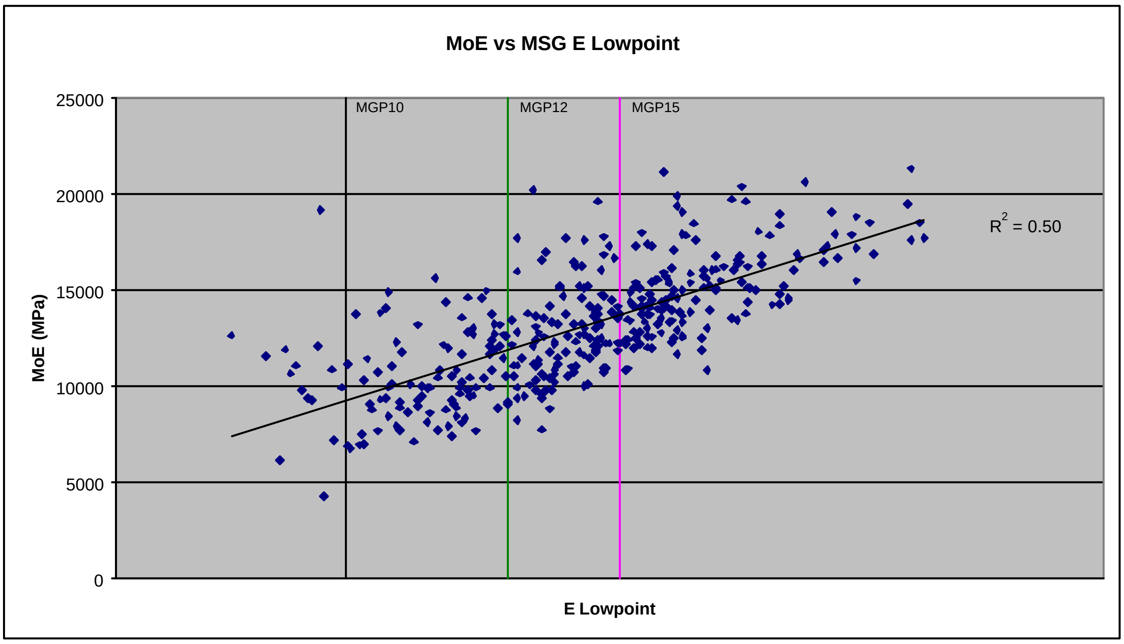
Figure 1 highlights a typical E profile for a board. In this example:

- The minimum E value is greater than the MGP10 threshold, and therefore board would be spray-marked MGP10
- Under the 'one grade per piece' rule the entire board is considered MGP10 grade, even though sections of the board exceed the MGP12 and even MGP15 thresholds.
- This board is 5400mm in length – but as highlighted by the E profile, the mechanical stress grading process cannot identify the local stiffness of the leading or trailing ends (around 780mm)

Stage 2 – Visual grading

- This board would continue to the visual grader who has the task of identifying strength and utility-limiting characteristics, and assessing these in accordance with AS/NZS 1748 and any specific producer-defined rules.
- The grader may well find that, even though the board has been marked as MGP10, there is a characteristic that is outside the limits permissible. For example, the E-lowpoint may coincide with a 60% KAR knot. Although the knot did not reduce the local stiffness sufficiently for the board to fall below MGP10 requirements, it is recognised as being of significant strength-limiting impact and therefore the board must be downgraded with a 'visual override'.
- The board can be docked to remove the offending characteristic.

Figure 2 compares the grading modulus (E lowpoint – horizontal axis) to average MoE (random sample & test location on edge – vertical axis) measured for a



typical population.

Fig. 2: MoE (random sample/test on edge) vs MSG E Lowpoint (typical 30yr old Australian radiata)

The inherent variability in the stiffness of the radiata feedstock means that boards will be sorted into each of the three MGP grades as well as the 'non structural' grade which represents sub-MGP10 threshold. The threshold values for the MGP grades are highlighted. Key points of interest are:

- The random MoE measurements vary from 4,200MPa to 21,000MPa with a coefficient of variation (CoV) of around 23%. The CoV within the MGP grades is less (14% for higher grades).
- The strength of the relationship between the grading modulus and the stiffness parameter is defined by the coefficient of determination – which for this population is $r^2 = 0.50$. This means that 50% of the variation in MoE can

be explained by the linear regression line through the points on the E lowpoint axis.

- Although the mechanical stress grader measures stiffness accurately, we are trying to correlate the minimum stiffness measured on flat along the board to the average stiffness on edge, at a random location – which contributes to the relatively poor correlation.

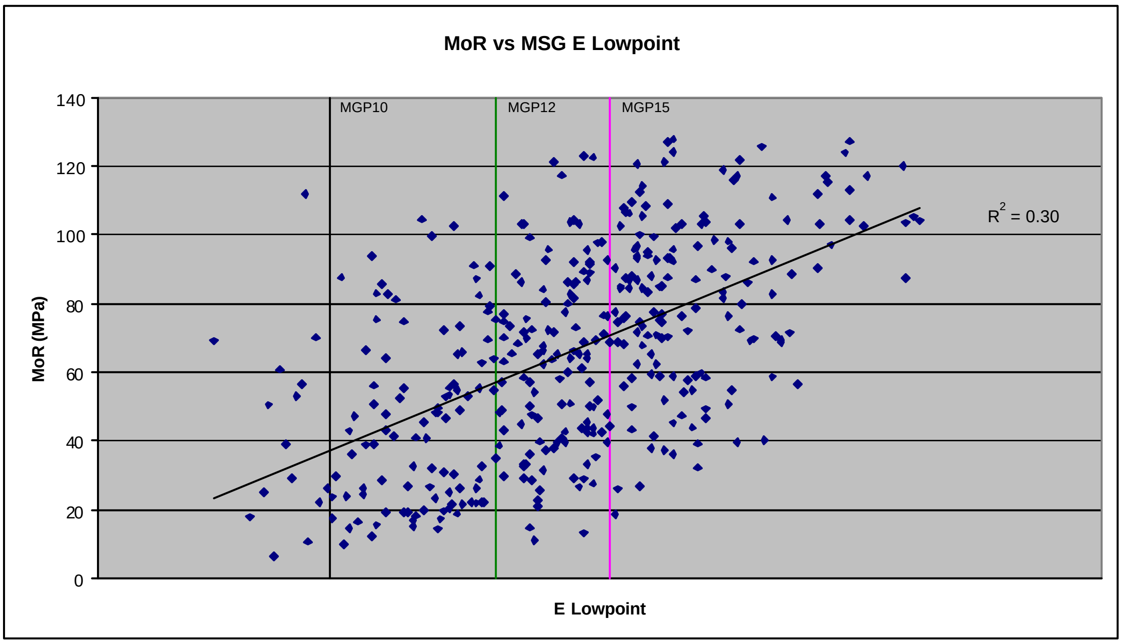


Fig. 3: MoR (random sample/test on edge) vs MSG E Lowpoint (typical 30yr old Australian radiata)

Figure 3 compares the grading modulus (E lowpoint – horizontal axis) to 5th percentile MoR (random sample & test location on edge – vertical axis) for the same population. MGP grade thresholds based on E lowpoint are again highlighted. In the case of the strength parameter:

- The random MoR measurements vary from around 10MPa to 130MPa with a coefficient of variation (CoV) of around 45%.
- The larger overall CoV compared to random MoE can be clearly seen in the greater vertical spread of data points. The CoV for MGP10 MoR is as high as 50%, while MGP12 and MGP15 are 36% and 30% respectively.

- The r^2 = 0.30. This means that only 30% of the variation in MoR can be explained by the linear regression line through the points on the E lowpoint axis.

- The reason for the poorer correlation compared to MoE is simply that the stress grading process is designed to measure stiffness on flat (and sort by E lowpoint on the board) and predict the structural properties of stiffness on edge and strength on edge – it is a better predictor of stiffness.

Figure 4 now compares the two structural characteristics predicted by the grading modulus – random MoE vs. random MoR (random sample/combined test on edge). The strength of the relationship between the predicted parameters is around 46% (r^2 = 0.46). This plot clearly highlights the loss of definition at the grade boundaries expected from the grading regime (grade shown using colour coding).

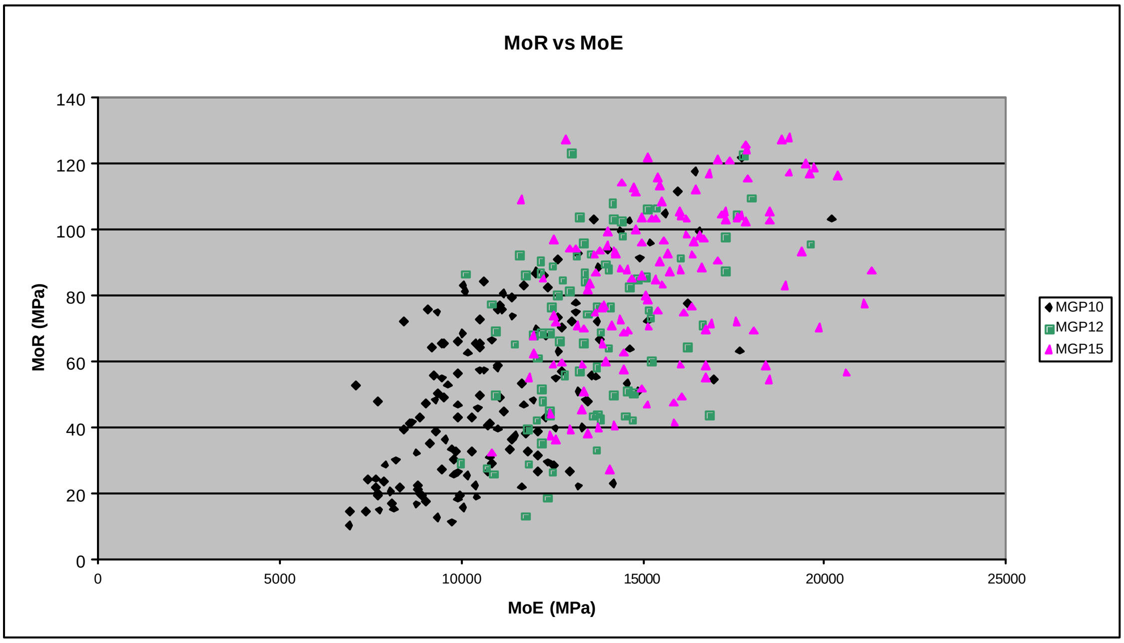


Fig. 4: MoR vs MoE (random sample/random test on edge)
(typical 30yr old Australian radiata)

The loss of definition at the grade boundary leads to ‘overgrading’ and ‘undergrading’. Overgrading represents the case where inferior strength or stiffness material is allowed to enter a grade, while undergrading represents the case where superior quality material falls down into a grade.

Overgrading is a risk that must be minimised through stringent quality control (QC) practices, while undergrading represents an opportunity-lost because material is being undervalued.

In terms of QC, MGP producers must have in place a robust continuous monitoring regime. The aim of continuous monitoring is to determine the properties of a population based on a small sample. All sample results will have a confidence interval within which you can assume the population’s actual properties lie – ie. With a confidence level of 90%, the confidence interval is +/- 5%. The greater the variability of a parameter, the more samples that are required to achieve a predefined confidence level.

Hence, given the greater variability of MoR compared to MoE within grades, you must test the bending strength of more samples to achieve the same confidence level for the MoR result as you do for the MoE. This can render QC continuous monitoring a resource-intensive exercise.

Another issue to contend with is how to meet the properties of a grade through adjustment to the grading modulus. The impact on a population’s MoE and MoR values due to changes in the MSG E lowpoint threshold are directly related to strength of the respective relationships to E lowpoint. MoR is less sensitive to E lowpoint changes – which in turn can be detrimental to grade recovery and the undervaluing of higher strength boards.

Giudiceandrea (2005) discusses these concepts and recreates a table from Glos (2004) that compares the coefficient of determination between timber strength and MoE, which is relevant to existing MGP grading, alongside other grading modulii measured using some of the technologies to be discussed in this report (refer Table 2).

Indicating properties to predict timber strength (Grading modulus)	Coefficient of determination r^2
Knots	0.15 – 0.35
Density (using x-ray etc)	0.20 – 0.40
Frequency (acoustics)	0.30 – 0.55
Modulus of elasticity	0.40 – 0.65
Knots & density (data combined)	0.40 – 0.60
Knots & density & frequency	0.55 – 0.80

Table 2: Coefficient of determination for timber strength – comparing grading modulii (Timber species not defined)

The combined indicating properties that deliver a better r^2 than MoE alone represent potential for better prediction of strength. This is a particularly important observation that should be kept in mind when considering the remainder of this report. Use of one grading technology alone is unlikely to produce a 'quantum' improvement in strength prediction. Combining technologies appropriate to a specific resource has the potential to deliver significant improvements to strength prediction provided the technologies are carefully selected.

4. CLASSIFICATION & ANALYSIS OF GRADING SYSTEM TECHNOLOGY

4.1. Classification by Grading Modulus

A grading modulus simply represents the parameter that a grading machine measures and subsequently uses to sort material into different grades.

4.1.1. Overview

The 12 systems investigated can be broken up into 4 general groups based on the combination of grading modulii used to make grading decisions. The number of discrete grading modulii also totals 4:

- Measurement of board stiffness (MoE) mechanically
- Measurement of acoustic velocity within the board
- Measurement of external characteristics
- Measurement of internal characteristics

Figure 5 lists the grading modulii and highlights which systems fit into which group based on this. The following sections provide a discussion on the application of technology to measure the grading modulus.

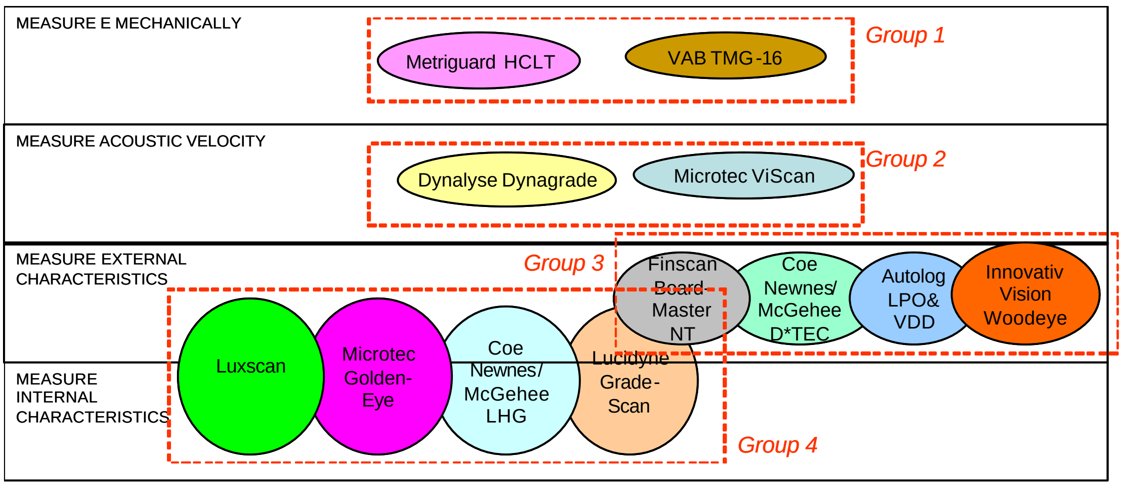


Fig. 5: Classification by grading modulus

4.1.2. Measure E Mechanically

The stiffness of a body describes its ability to resist deformation due to the application of a distributed force (stress). A significant number of structural applications require softwood timber to resist bending forces – either edgewise bending (where the board acts like a joist and the bending force is applied in the plane of the wide face) or flatwise bending (where the board acts like a plank). The stiffer the timber, the more force will be required to deflect it by a given amount.

The general relationship between a board's stiffness and bending strength is well known, but around the 1960's international research directed attention to the manufacture of mechanical 'stress grading' machines that were designed to mechanically measure timber stiffness. This allowed sorting not only by stiffness properties, but as a prediction of bending strength.

The mechanical aspect of the grading technology relates to the requirement to physically bend the sample. The stiffness is a function of the resulting deflection and the reactionary force of the timber to resist the bending. While this deflection remains linear relative to the applied force, the stiffness is termed the modulus of elasticity (MoE).

The majority of mechanical stress grading machines have followed the lead of initial designs – where boards are fed into the machine linearly and on-the-flat. Depending on the design, the machines then guide the board through a precise, constant deflection path and use a load cell to measure the force required to bend it over this preset span. Other machines apply a constant bending force as the board passes through the machine and measure the deflection that each board achieves.

Whichever method is used, the result for a linear fed machine is that a stiffness 'profile' is developed along the board as subsequent sections pass through the bending zone (which is typically 3-4 feet in span). The 'local' MoE at any point on the board is therefore dependent on the stiffness attributes of the wood fibre on each side of the point, to the limit of the bending span.

Also typical of these designs is duplication of the bending action within the machine – bending it in one direction followed by the other. This mitigates the effect of naturally curving boards.

Linear machines can typically output two grading modulii:

- Average MoE – average of all stiffness measurements along the board length
- Lowpoint E – minimum 'local' E measurement recorded along the board length

Another machine design that has emerged in recent years that will be discussed in this report is a mechanical stress grading machine that feeds the boards into the machine on a transverse conveyor. A central 'shoe' then causes the boards to deflect downwards by a preset amount while load cells near each end measure the reactionary forces. This is followed by an upward forcing deflection allowing summation of all loads to be used to calculate an average MoE for the board.

A transverse machine can output only the average MoE as a grading modulus.

Mechanical stress graders allow the operator to sort material on the basis of stiffness – which (as highlighted in the previous section) has a correlation to strength.

Mechanical stress graders are also sensitive to a number of other wood characteristics due to their impact on stiffness. These include slope of grain and microfibril angle – both of which are important for accurate strength prediction.

'Slope of grain' is a term used to describe the orientation of wood grain relative to the long axis of a tree trunk (or single board). The grain orientation is itself determined by the alignment of wood fibres. Due to the anisotropic nature of the wood structure, stiffness and strength are much greater parallel to the grain than fibres that are perpendicular to it. Boughton & Crews (1998) state that "the strength parallel to grain can be up to 100 times that perpendicular to grain. The strength at other angles can be interpolated between these two extremes".

Although the slope of grain can be identified visually on the surface of a board, it is very difficult to quantify its significance to stiffness and strength – especially at production speeds. By measuring stiffness though, a producer has some ability to indirectly control slope of grain effects.

The microfibral angle (MFA) is another characteristic that affects strength and stiffness. The MFA can only be determined at high magnification of the wood fibre walls – and is therefore impossible to directly measure in a production sense. The MFA refers to the "mean helical (spiral) angle that the fibrils of the S2 layer of the fibre wall make with the longitudinal axis of the fibre" (Jozsa & Middleton, 1994). Mature wood is characterised by a small microfibril angle, while juvenile and compression wood have higher microfibril angles. In the case of juvenile wood, Jozsa & Middleton conclude "these large fibril angles in juvenile wood have been correlated to lower strength and stiffness in lumber products where these lower values could not be attributed to appreciable differences in density". As with slope of grain, by measuring stiffness directly, mechanical grading machines are also responding to the effects of MFA.

4.1.3. Measure Acoustic Velocity

Measurement of acoustic velocity is a non destructive test method based on the principle of sonic resonance. This principle has been used in timber industry applications for over 20 years, beginning initially with 'stress wave timers' to detect rot in utility poles (Andrews, 2002).

The machines discussed in this report rely on the same basic premise – that longitudinal excitation of a length of timber, for example via a hammer impact, will setup low frequency stress waves that propagate back and forth throughout the board. By measuring the resonant frequency of the stress waves, and by knowing the length of timber you can deduce the acoustic velocity:

$V = f.?$

where $V =$ Acoustic velocity (ms^{-1})

$f =$ Resonant (fundamental) frequency (Hz)

$? =$ Wavelength (2 x board length)

Acoustic velocity relates to density and dynamic stiffness via the following equation:

$E_{dyn} = ?.V^2$

where $E_{dyn} =$ Dynamic stiffness (Pa)

$? =$ Density ($kg.m^{-3}$)

The use of sonic resonance assumes that the timber board acts as a rod-like structure and that the stress waves are planar in motion – where all elements in a cross section compress and expand identically in the longitudinal direction. This is achieved because the boards ends work effectively in reflecting the stress waves back and forth such that planar waves are setup after the initial point impact, and because the low frequency excitations have a relatively large wavelength that allows the wave to travel long distances.

The grading modulus – acoustic velocity (V) – is directly related to the average dynamic stiffness of the board. A stiffer board will deliver a higher acoustic velocity measurement.

The grading modulus represents an average over the entire length of the board. This has the advantage that it is a grading modulus that has taken into account the entire volume of the sample, unlike (for example) a grading modulus that measures surface characteristics and infers internal characteristics. What is yet to be discussed is whether acoustic velocity provides enough information about local characteristics to be effective as a predictor of strength.

There are numerous studies available that highlight the merits of acoustic velocity measurement for softwood grading. Halabe et al (1995) provide a summary of historic research, including regression models correlating stress wave velocity to static bending MoE for different species of dry wood. The coefficient of determination (r^2) values here ranged from 0.61 to 0.9. Correlations to MoR were less (between 0.34 to 0.56) as is the case with traditional mechanical E measurement. More recently Gaunt & Emms (2004) highlighted r^2 correlations greater than 0.90 for acoustic velocity-derived dynamic E versus static MoE (on-edge and on-flat) using a Forest Research ‘A-Grader’ machine.

Variations in the technology are also well established for sorting lumber in the green state, for sorting logs prior to processing and for assessing standing tree stiffness (using ‘time of flight’ measurements). Amongst other things, all of these applications have significant implications in terms of quantifying resource value prior to cost-adding processing.

4.1.4. Measure External Characteristics

The scope of external characteristics in softwood material is significant. The list below highlights some of these characteristics:

- Geometric parameters - length, width, thickness, wane, bow, spring, twist, cracks
- Biological characteristics - knots, pith, resin pockets, stain and rot
- Manufacturing characteristics – tearout, skip, materials handling damage

Effective grading of these characteristics demands not just accurate identification and measurement, but also accurate classification. This implies that the grading system must have the ability to first identify a characteristic using a combination of the technologies discussed below. It must then accurately measure the characteristic and classify it. Only then can the data be considered a grading modulus suitable for grading relative to predefined rules.

The processing intelligence required to achieve this point should not be underestimated. Take for example the variability in knots within softwood. The look of a knot can vary significantly from one to the next – in terms of size, colour, location, bark encasement, sound or unsound relative to surrounding fibre, cracked or even missing completely (ie. knot hole). Knot material can be apparent across one or more faces depending on the knot type, which itself is dependent on the proximity and connection of the knot to pith material. Effective visual size classification of a knot in the Australian context for visually grading radiata demands that the knot be measured as a knot area ratio (KAR) of the cross-section. To determine the ratio of knot to overall cross-section therefore also requires the system to infer the knot direction and shape within the material.

The grading systems discussed in this report employ a combination of technologies to measure external characteristics:

- Laser triangulation
- Camera scanning for colour and shape
- Camera scanning for laser tracheid effect

LASER TRIANGULATION

The three dimensional shape of a board along its full length is critical to grading for geometric parameters. Measurement of the board profile using 'laser triangulation' replicates this visual task.

'Laser triangulation' is not a new technology, having been used in the wood industry for many years. The system employs pairs of laser and charge couple device (CCD) cameras to scan each of the four board faces. The laser projects a line of light across the face which is reflected back through a lens into the CCD camera (see Fig. 6 for an example of a laser/camera pair).

Fig. 6: Example of laser triangulation sensor for geometric scanning (courtesy: Autolog)

The camera consists of many individual light sensitive pixels that are capable of storing electronic charge created by light absorption. In this way the CCD can accurately track changes of the reflected laser beam due to variation in the surface profile. The accuracy of the technology to measure board shape is dependent on scanner resolution and production speed.

CAMERA SCANNING

CCD cameras are also used to identify variations in surface colour along the length of a face. Different manufacturers have used different strategies in camera scanning in terms of choosing colour cameras (RGB) versus black & white. Both achieve the task of identifying relative darker and lighter objects on a board, while those using colour cameras also rely on the different colour outputs to assist in classification. Figure 7 provides an example of a camera scanning frame (4 sensors) that delivers 4-face linear scanning.

Fig. 7: Example of camera scanning frame – each of the 4 sensors houses a camera and light source (courtesy: Autolog)

All systems rely on a light source to assist in developing suitable contrasts between parent material and specific objects. With the scanned solution from each face, the systems then classify certain characteristics by their colour (relative darkness), shape, size and relationship to objects on the other board faces.

TRACHEID EFFECT

The tracheid effect relies on the principle that wood fibres act like optical conductors. The parallel wood fibres in softwood are known as tracheids – the tracheid effect measures the ability of these fibres to scatter laser light. Nystrom (2002) describes this technique: "when a narrow beam of light strikes a wood surface, a part of the light penetrates into the outermost layers of tracheid fibres where it is scattered and conducted, better in the direction of fibres than across them".

The key to this technology is that healthy clear wood fibres will conduct the light well, whilst certain characteristics limit the transmission. Hence, if a camera sensor is focused just ahead or just behind a narrow laser line on the wood surface, the extent of the tracheid effect can be measured (see Fig. 8 for an example of the tracheid effect).

The tracheid effect can be employed to assist in the classification of a number of characteristics, including:

- Sound knots – where the wood fibre deviates significantly around the knot
- Decay
- Juvenile wood and compression wood
- Bark

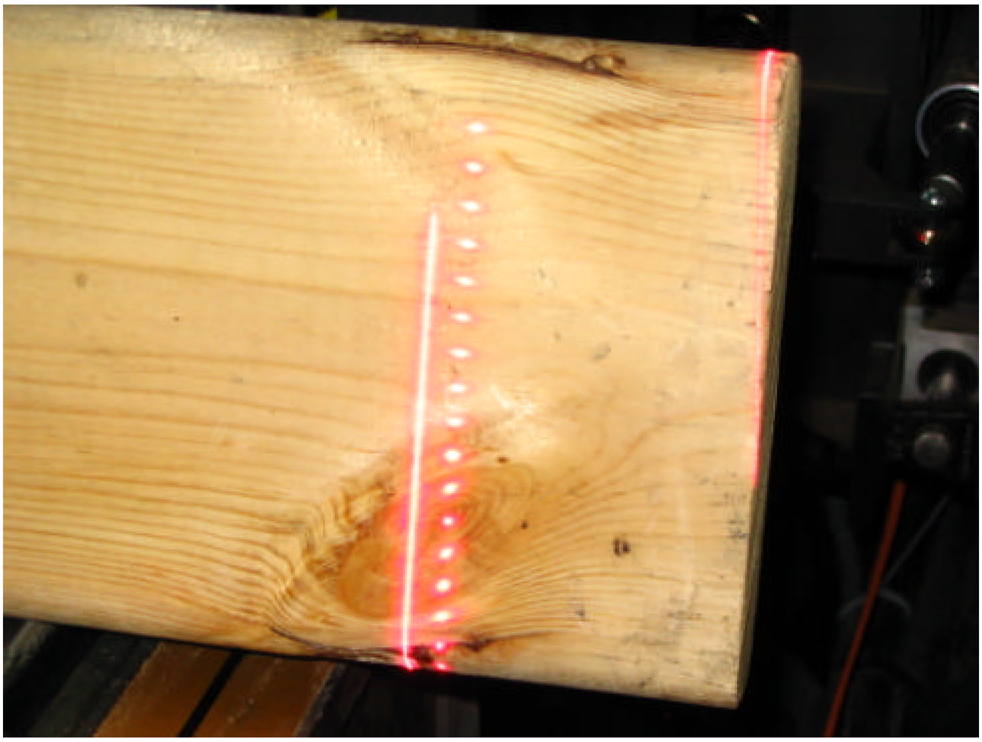


Fig. 8: Example of tracheid effect – note the change from elliptical shape for laser dots within knot material (COE Newnes/McGehee LHG laboratory)

4.1.5. Measure Internal Characteristics

Internal characteristics include density and moisture content. Several systems use x-ray technology to map the absolute density profile along the length of a board while another manufacturer uses radio frequency dielectric sensors to produce a density map. There are two objectives for developing a density profile along a board. The first is to use the density as a grading modulus for predicting local strength and stiffness. The second is to allow a means of measuring knot and pith location, size and direction within a cross-section.

The measurement of moisture content is also used in conjunction with density to predict bending strength. The primary means of measuring moisture content is via microwave transmission, which can also quantify 'bulk' grain angle.

X-RAY SCANNING

Research into x-ray scanning for the purposes of predicting softwood strength is not entirely new – with Weyerhauser developing the concept over 10 years ago. The method relies on the variation in density between clearwood and knot material – with knots typically twice as dense as clearwood. If you pass x-rays from a source through a sample of wood and onto a detector, part of the radiation will be absorbed by the wood. The amount of absorption depends on the density of the material. Water can also absorb the x-ray radiation, and this is one reason for moisture content measurements to confirm the presence of water in the wood.

Using this form of non-contact sensor you can develop a density profile with spatial measurement resolution of about the same scale as the knots which represent the greatest strength-reducing characteristic in the wood. Schajer (1999) describes an estimated board strength profile that is a function of clearwood density (the higher the density, the greater the clearwood strength) and some 'wood structural factor' that represents the amount of strength reduction from idealised clearwood due to a non uniform structure (such as knot or grain distortion – the larger the knot the larger the localised density increase, and the larger the 'wood structural factor').

Schajer (1999) reports correlation coefficients between estimated and measured MoR in the range of 0.68-0.78. This compares to correlation coefficients between measured MoE (using traditional stress grading machines) and measured MoR of 0.50-0.60. The species in question was southern yellow pine.

DIELECTRIC SENSOR

When a radio frequency field is setup to penetrate through the cross section of a board, the material's response is related to its dielectric permittivity. The dielectric permittivity is described by the dielectric constant, which measures how much electric field is stored in the volume of wood, and the loss factor which measures the proportion of electric field energy converted into thermal energy within a volume of wood. These dielectric properties are themselves related to the physical properties of the wood – including density and moisture content.

Determination of the dielectric constant using radio frequency fields has in the past been used in the areas of timber drying and gluing, but it is equally applicable for detecting internal characteristics such as knots, spiral grain, slope of grain and structural discontinuities (Bucur, 2004).

The technology is non-contact, and employs radio frequency transmitters and antenna probes in close proximity to the wood to develop a density map.

MICROWAVE

The principle behind the use of microwave technology for the measurement of moisture content is the same as that for radio frequency fields and density – namely the response of a material due its dielectric constant when exposed to the electromagnetic wave.

In this case studies have shown that by measuring the reduction in speed of a linearly polarised, plane microwave transmitted through wood provides a useful indication of moisture content. As well as speed retardation, the wave will become depolarised – emerging instead "elliptically polarised with its minor axis in the direction of the maximum dielectric constant, which is essentially the direction of grain" (James, Yen & King, 1985).

4.2. Classification by Transport System

4.2.1. Overview

The 12 systems investigated can be broken up into 2 general groups based on the method of board transport. Figure 9 highlights those systems grouped as 'linear' versus 'transverse' according to board transport. The following sections highlight some of the considerations for each method.

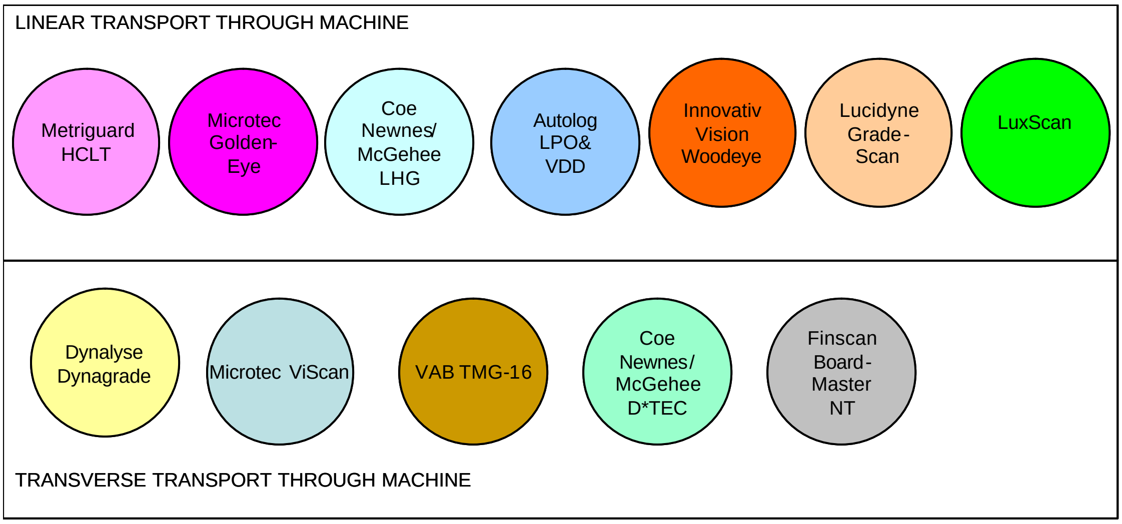


Fig. 9: Classification by transport system

4.2.2. Linear Transport

The manufacturers of linear systems see a major advantage of this design to be the minimisation in the number of sensors. With the boards travelling lnearly through a sensor frame, only one set of sensors is required per face. This compares to the array of sensors needed to scan the face of a board travelling in a transverse direction. By minimising sensor cost you can maximise scanning resolution, and Autolog (for example) state that the maximum 1" scan resolution currently available for transverse sensors on the market is not accurate enough. The 'bolt-on' addition of new sensors is considered to be more viable with linear systems too.

Lucidyne believe that system performance is very much reliant on the ability of the scanning processor to accurately register all sensor outputs together. This is easier to achieve with linear scanners, since transverse systems must ‘marry up’ outputs from many more sensors. Further to this, a linear system may be the only option for effective implementation of a tracheid sensor.

In terms of production line efficiency, a linear system may fit into the flow of a planer mill better – with most systems capable of being close-coupled to the planer. The systems also dispose of the need for chains and lugs that could cause material marking or damage.

One of the biggest issues with linear systems is board tracking. Boards are scanned prior to being loaded into lugs for trimming and sorting into bins. This means that each board’s unique grade ‘solution’ must somehow be assigned physically to the piece during the scanning process. This grade mark is then read once the boards are in lugs ready for trim decisions etc. Most systems employ some sort of high speed inkjet or UV code printer and reader – but it is acknowledged that these can be the ‘weak link’ in terms of reliable high speed production.

4.2.3. Transverse Transport

The potential weakness in board tracking inherent in linear systems is not an issue with transverse systems. Boards are already loaded into lugs in preparation for scanning – with most systems using a short speed-up belt to momentarily isolate the boards from the lugs during actual scanning.

In terms of geometrical measurements, transverse scanning systems hold an advantage in terms of twist measurement. With the board travelling unrestrained within a lug space (on the speed up belt), the twist along its length can be accurately measured using laser profiling.

Linear systems are not able to directly measure twist, since boards are restrained in this direction by infeed-outfeed rollers. Instead, installations use a separate laser scanner downstream once the boards are in lugs to specifically measure twist. Some systems also predict twist magnitude based on the amount of ‘squash’ seen at the rollers as boards pass through the linear sensor frame.

Another advantage of the transverse systems is the ability to more readily cope with higher production rates. A number of the transverse systems – including the Dynagrade and VAB TMG-16 were actually designed with the intention of improving production rates over existing linear alternatives (although we are now seeing systems such as the Metriguard HLCT boosting production speeds).

The method of measurement for systems such as the Dynagrade and ViScan – where a longitudinal stress wave is induced along a board - also lend themselves to a transverse board flow.

5. GROUP (1) – MEASURE E MECHANICALLY

5.1. Metriguard – Model 7200 High Capacity Lumber Tester (HCLT)

5.1.1. *History*

The company Metriguard, based in Pullman (Washington State) came into existence in 1972. At this point in time a preceding company had produced seven lumber testing machines designed to measure the stiffness profile of structural lumber. The original machine design has endured, only being discontinued in 1995. It is a testament to this design that four of the original seven machines are still in operation.

Metriguard's current mechanical stress grader is the Model 7200 High Capacity Lumber Tester (HCLT). There are currently around 65 of these units in operation around the world, together with around the same amount of older CLT machines. The markets where these machines are located include:

- Australia
- Europe
- Japan
- New Zealand
- North America
- South Africa

5.1.2. *Machine Description*

The Metriguard Model 7200 HCLT uses one of the more 'traditional' designs for mechanically measuring stiffness – namely a linear flow via which each board is subjected to a constant deflection down and then up, with the load measured during each deflection. This allows a stiffness profile to be developed, with grading modulus a combination of E lowpoint and/or E average (as well as the newly introduced 'limit-ratio' – represents ratio of lowpoint to average).

The machine uses a PC data system (PCDS2) for processing measurements, grading and initialising grade marking (sprays). The data system also records production statistics (refer to Fig. 10 for a general view of the machine).

To facilitate remote assistance, each Model 7200 HCLT is shipped complete with a modem.

In terms of production capabilities, the machine is now rated for production speeds up to 914m/min (3000 ft/min – currently employed at this speed in a mill in Canada). Product sizes range from 2.5 – 9m in length, 63 – 286mm in width and 35 – 45mm in thickness.

Fig. 10: Metriguard Model 7200 HCLT (courtesy Metriguard website)

5.1.3. Design Considerations

The design principles behind the Model 7200 HCLT are 'industry proven', with the basic concepts unchanged for 30+ years. This remains true for Australian conditions, where the Metriguard is the primary tool for mechanical stress grading of MGP.

The Model 7200 has been designed to mitigate production flow issues such as jamming of broken boards. The focus for the design now is continuous improvement:

- Increasing production speed capabilities
- Improving reliability of mechanical components
- Improving reliability and stability of PC architecture/communication – switch to LINUX environment
- Development of system inputs such as moisture meter data
- Development of temperature compensation technology – this technology (currently in beta test) uses an infrared temperature sensor to determine board temperature at the machine infeed. The grading system can adjust measured stiffness due to temperature variation, such as the case in cold environments where material is exposed to freezing conditions prior to processing. This is important, given that stiffness increases with reducing temperature – and in these cases the machine may be overestimating product grade (relative to final application).

5.1.4. <u>Perceived Benefits</u>

Metriguard believe that the significant benefit in mechanically measuring stiffness is that it responds to the critical wood characteristics of microfibril angle and slope of grain, which have a 'profound' effect on strength. The system also works reliably with varying moisture content. Moisture content (MC) does not affect the physical bending process but does impact stiffness – with increasing MC leading to a reduction in stiffness. This represents a conservative effect.

In contrast, Metriguard hold the view that machines which employ x-ray technology to predict strength using density (or specific gravity) react in an opposite way to MC – with higher MC interpreted as higher density and therefore higher strength.

Metriguard also perceive the act of physically loading the timber during production as a benefit – in that it represents a means of bending "proof stress screening" (Logan). Although the applied load is much less than the design requirements, it provides an opportunity to knock out very low strength 'bad actors' (ie. 'rogues') well before they reach the customer.

Metriguard see two general trends as being important for growth of their product:

1. Shorter resource harvesting cycles causing reductions in general fibre quality
2. Building practices that continue to push the limits of product design to maintain cost effectiveness.

The combination of these trends will make accurate, quantitative assessment of stiffness and response to MFA and slope of grain even more critical for timber reliability. They cite one example of a truss manufacturer that builds around 600 units per year. The manufacturer used to rely on a crew of 19 to carryout repairs on existing trusses (dimensional stability, strength issues primarily). With mechanical stress graded material, the manufacturer is benefiting from more predictable performance, quicker installations (no onsite changes) and much less repairs.

It is of interest to note that, unlike Australian softwood production, only around 7-8% of the North American market is mechanically stress graded (known as machine stress rated - MSR). The proportion of that market that represents MSR 'candidate' material is around 30%.

5.1.5. Metriguard's View of Scanning Technology

Metriguard firmly believe in the need for mechanical stress grading as part of the overall grading process. The company though is very much interested in automated scanning technology for classifying external characteristics. It acknowledges that visual grading rules can be somewhat vague and open to interpretation – which makes handing over these decisions to a computer processor very difficult and frustrating.

Metriguard have worked with scanning system manufacturers – primarily Autolog – to integrate stiffness profile data into final grading decisions.

5.2. VAB Solutions – TMG-16 Transverse MSR Grader

5.2.1. History

VAB Solutions market the TMG-16 Transverse MSR Grader. The company is located in Quebec city, and is relatively young - with two main promoters who have spent considerable time in the lumber production industry. VAB Solutions specialise in customised technological solutions for industrial measurement equipment relating to lumber, shavings, wood pulp and wood panels.

VAB Solutions also carry out research and development projects with business partners – such is the case for the TMG-16. This system has been designed by researchers at the Centre de recherché industrielle du Quebec (CRIQ). CRIQ is a government research body created in 1969 to provide innovation and expertise in the areas of manufacturing technology, environment, industrial information and standardisation. They have significant resources dedicated to the Quebec wood products industry.

The TMG-16 grades timber based on mechanical measurement of average stiffness. Unlike the Metriguard HCLT, the TMG-16 assesses boards travelling in transverse conveyor lugs. Three systems have been installed since commercialisation of the machine 3 years ago. The systems are all located in Quebec. The timber species in each case is a mixture of spruce, pine, fir (SPF).

The primary goal for the system is to provide mill operators with an MSR grading solution that can run at production speeds in excess of 200 lugs/minute, and which has a small machine footprint.

5.2.2. Machine Description

As the name suggests, the Transverse MSR Grader is designed for applications where the planed material is travelling in a transverse flow. The TMG-16 is designed to process timber of length 1.5m – 4.8m with North American cross-sections 2x3, 2x4 and 2x6. The machine comprises of a transverse frame and substructure 1.9m in length, 6.8m in width and overall height 2.4m. The machine also employs an integral chain conveyor that extends 4.2m in total through the frame. Refer to Fig. 11 for a general view of the TMG-16.

The mechanical measurement of stiffness is slightly different for long boards versus shorter material. When running long length boards (4.2 - 4.8m), the measurement process is as follows:

- The timber, indexed to a zero line, is loaded into lugs as it is passed onto the integral chain conveyor
- As it enters the frame, two pressing shoes suspended from above cause the timber to deflect downwards at the 1.52m and 3.35m location from the zero line (see Fig. 12).

Fig. 11: VAB Solutions TMG-16 (CRIQ laboratory)

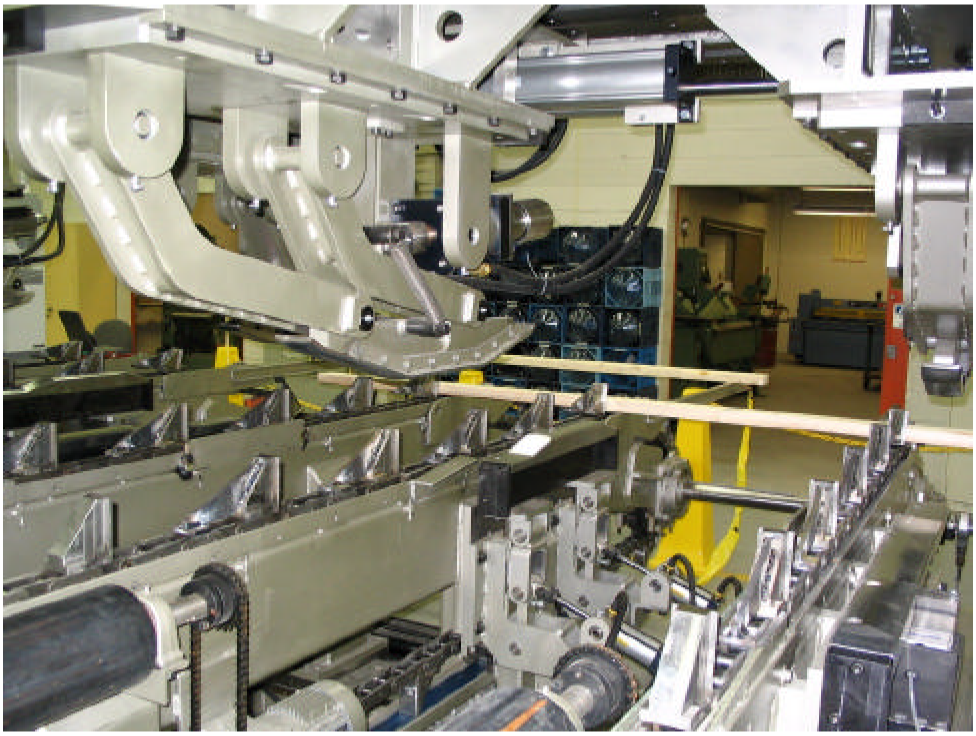


Fig. 12: Overhead pressing shoes – impose downward deflection

- The pressing shoes are designed like a rail to gradually introduce the deflection, which for full length boards is around 12mm.
- Three underside 'shoes' located within the conveyor structure at the 0.61m, 2.44m and 4.27m provide resistance to the downward deflection – effectively producing two 0.91m bending spans
- Integral to the underside 'shoes' are load cells that measure the relative components of the downward forces (see Fig. 13)

Fig. 13: Underside shoe with integral load cell for measuring resistance to deflection (CRIQ laboratory)

- The timber continues further into the frame and is then subjected to upward forces from another two pressing shoes – this time located in the conveyor structure
- Three overhead shoes act together to again resist the force and produce the two 0.91m bending spans. Load cells in the overhead shoes measure the resistance.
- With the board subjected to the bending reversal, the combined forces measured at all load cells are used to calculate an (on flat) average stiffness (Eaverage) for the piece
- Only one grade is awarded per piece
- The maximum overhang at each end of the bending spans is 0.61m

For shorter boards (1.5 – 3.6m) the deflections are single span – with only one pressing shoe working in combination with a pair of resistance shoes. Unlike the longer boards, the span required to produce the appropriate deflection represents the majority of board length. See Fig. 14 for an example of a short board undergoing deflection.

The system uses a Labview graphic program interface for the grade threshold setup, production control and shift statistics. The software maintains a buffer of 5000 pieces. Three grades can be processed simultaneously, with the software also controlling spray marking.

Span adjustment for board length is automated, with the lug chains connected to pneumatic cylinders that initiate lateral movement for realignment. The overhead shoes are also able to move laterally to ensure correct span setup. The deflection amplitude is controlled by changing the height of the transverse frame. This is also automated with pneumatic cylinders and shim insertion.

The machine has been accrediated by the Canadian Lumber Standards Accreditation Board for production speeds of 200 lugs/min. CRIQ personnel confirmed that existing clients are running at these speeds.

5.2.3. Grading Modulus

The TMG-16 uses the average MoE (on flat) as the grading modulus for sorting timber. As part of the measurement of MoE (on flat), the timber is deflected in two directions to eliminate the effects of natural curvature as well as the potential uneven impact of a characteristic.

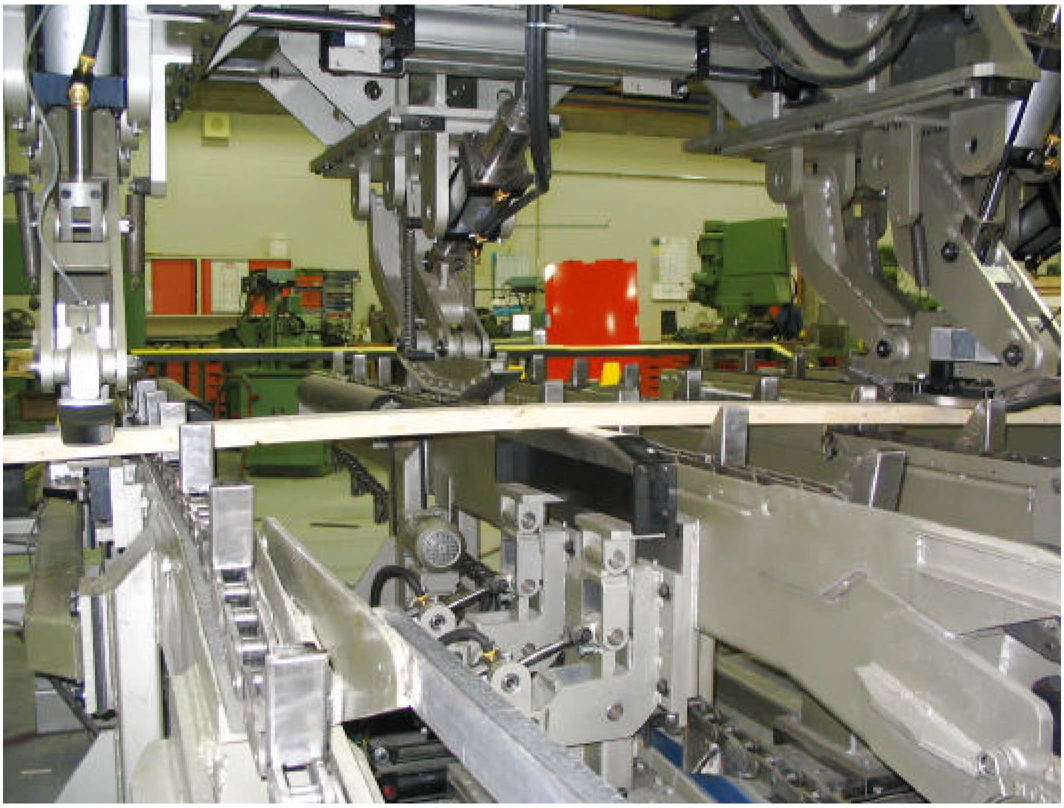


Fig. 14: Short board undergoing upwards deflection via single underside shoe (CRIQ laboratory)

Thresholds for this grading modulus are designed to deliver grades where the population's overall average MoE (on edge) meets a specific design value. As part of the machine accreditation process (to Canadian Lumber Standards), testing was completed to confirm the strength of relationship between the grading modulus and average MoE (on edge), as measured by a static bending machine. The result was a coefficient of determination $r^2 = 0.8905$ – based on measurement of various length and cross sections at 200 lugs/min. CRIQ believe this correlation can get as high as $r^2 = 0.95$ when sampling within a specific size (eg. 2x3).

CRIQ believe that one of the benefits of their machine configuration relative to grading modulus is the measurement precision at high production rates. The machine uses an encoder and photoeye to synchronise the start of data collection as each board begins its loading cycle. Once measurement is started, the software can acquire around 150 – 200 discrete data points from each load cell during the short time that the board is travelling across the shoes.

As mentioned, the only species that the machine currently processes is SPF. In terms of relevance to radiata this is not a significant concern – as the measurement process is the same for all species.

5.2.4. <u>Design Considerations</u>

The TMG-16 has been designed to minimise downtime and machine damage due to material blockages. Alongside production capability and compact footprint, this reliability factor was driven by customer needs. Specific 'protection' features include:

- A photoeye and board sensing 'whisker' are located immediately upstream of the machine and can detect on-edge or doubled up boards. When this occurs the overhead shoes retract to protect the assembly.

- The overhead pressure shoes are actually held in location by pneumatic cylinders with a force greater than that required to bend the timber. If the force required to bend the timber exceeds a certain level the arms will also retract for protection.
- For ease of use the upper arms and lower skids can be retracted and lowered manually during production of non-MSR material (eg. studs). This process takes less than 5 minutes.

Other important design features include:

- Rigid frame construction to mitigate any effects of structural flexure that could introduce error into the load/deflection relationship
- Minimal number of drives for synchronisation and control of timber flow

5.2.5. Quality Control

In accordance with Quebec grading agency requirements, the TMG-16 has a machine control procedure that must be completed at the beginning of each shift and every 4 hours thereafter. The 5 minute QC check includes general machine conditions – verification of the position of the deflection assembly, load cell reset and pneumatic gauge pressures checks.

The operator must then perform a quasi-static bending test with an aluminium bar of known stiffness. Essentially an accuracy test, the load cells must confirm the bar stiffness to within predefined tolerance. If the test indicates an 'out of control' condition there is an intensive testing procedure required to regain control, involving 8-way passes of multiple pieces with associated repeatability tolerance limits.

5.2.6. ***Perceived Benefits***

CRIQ personnel believe that the TMG-16 solution offers users a payback period of less than 1 year. The context for this scenario is changing from production of visually graded timber to MSR timber with the associated price premium. The perceived benefits of the system are:

- High production speed capability – without loss of measurement precision
- Machine footprint less than 6 feet in length
- Superior machine reliability with blockage and damage prevention
- Low maintenance requirements

It should be noted that CRIQ, like Metriguard, see the TMG-16 as one integral part in the overall grading process – alongside visual grading (or scanning) for strength and utility-limiting characteristics.

6. GROUP (2) – MEASURE ACOUSTIC VELOCITY

6.1. Dynalyse – Dynagrade

6.1.1. History

Dynalyse was started in 1995 by three doctorate engineers from Chalmers University (Sweden). Prior to this, Dr Mikael Perstorper (Managing Director) had done a significant amount of analysis on the correlation between stiffness and strength, and found that – for the local spruce timber – there was no real advantage in measuring an E lowpoint when predicting strength. This led to the design of the Dynagrade system.

The launch of the Dynagrade system coincided with a move to full stress grading of structural timber in Norway. At the time producers were trying to keep up with production demands using older bending-style stress graders that were either offline or only capable of relatively slow production rates (equivalent to around 20 lugs/min). This made it easy for mills to justify the Dynagrade – which is capable of at least 100 lugs/minute throughput.

The first system Dynagrade was installed in 1997. There are currently around 60 machines now installed in the following markets:

- Norway (accounting for approximately 85% of graded volume in market)
- Sweden (approximately 75% of graded volume in market)
- Finland
- Other markets – Baltic States, Eastern Canada

Timber that is processed with these machines ends up in Europe, USA and Japan. The specific grades include C18, C24, C30, with the majority of timber being Norway Spruce or Scots Pine.

The company remains relatively small, with a total of 5 staff.

6.1.2. Machine Description

The Dynagrade is installed after the planer and is designed for transverse timber flow. The system can accommodate timber of length 1.8 – 6.0m and various cross sections across the range 60x33 – 250x75mm. The machine itself is very compact and comprises of a main unit (incorporating impact hammer, sensors and analytical equipment), laser unit and belt drive system. The installed length of the components is around 1300mm, while the main unit rises just above the timber flow. Horizontal clearance required at either ends of the timber flow is less than 1200mm (refer to Fig. 15 for photo of an installed machine).

Fig. 15: Dynagrade Dynalyse – main unit obstructed by guard (Derome sawmill)

The measurement process is as follows:

- The timber, loaded in lugs on a normal chain conveyor approaches the machine fair-ended.
- Around 450mm before the sensors, the timber reaches a separate belt unit that causes it to rise slightly above the flow – in effect isolating one board from the rest.
- A very simple spring-loaded hammer is used to impact the timber on its end (at the lumber line). The flow of timber leading up to the unit initiates the hammer action.

Fig. 16: Detail of spring-loaded hammer & microphones (Derome sawmill)

- The hammer impact sets up a low frequency stress wave in the board. The fundamental frequency of this vibration is measured by two microphones that are located immediately downstream of the hammer, and in close proximity to the end of the board (see Fig. 16 for detail of hammer and microphones).
- At the same time, a laser unit at the far end of the board measures its length using triangulation principles (see Fig. 17)
- With vibration fundamental frequency and board length measured, the main unit can calculate the acoustic velocity for the piece. The acoustic velocity represents the grading modulus by which timber is sorted.

Fig. 17: Laser unit at far end – measuring board length (Derome sawmill)

The main unit houses a PC screen that displays:

- Current board information – grade and length
- Shift duration
- Shift production tally
- Bar chart highlighting grade recovery

The control system logs each board's grade, length and possible error message (due to signal quality issue) and controls board spray marking.

The system is presently designed for a production capacity of 100 lugs/minute. After a successful test series in early August (2005) monitored by the Swedish National Testing Institute (SP), Dynalyse are now seeking approval for speeds up to 240 pieces per minute.

6.1.3. Grading Modulus

The Dynagrade uses acoustic velocity as its grading modulus – with specific thresholds defined for the various structural grades. The system does not use MoE as its grading modulus, given that that it has no way of measuring board density (although a predicted MoE can be derived based on a constant, assumed density).

This grading modulus represents a 'global' parameter – it takes into account all characteristics within a piece and delivers a single value. This differs from linear bending machines such as the Metriguard HCLT as they have the ability to measure 'local' stiffness. That said, there is evidence – in the European context - that the Dynagrade delivers an equivalent correlation between grading modulus and strength.

Johansson et al (1998) compared the grading modulus for 4 machine stress graders against tensile strength for glulam lamination feedstock. The machines included the Dynagrade, Computermatic, Cook-Bolinder and Ersson (the latter 3 being 'traditional' linear bending machines). The coefficient of determination between indicating parameter and tensile strength varied from r^2 = 0.41 – 0.50 with the Dynagrade delivering the second best result with r^2 = 0.47.

Even more surprising is the fact that the Dynagrade produced the best correlation between knot area ratio (KAR) and grading modulus – with r^2 = 0.16 for tensile tests and r^2 = 0.20 for bending tests.

Dynalyse assert that the measurement of acoustic velocity is robust. It is relatively insensitive to material size and general surface finish (see note on impact surface below), as well as boundary conditions such board isolation and location of supports. These may account for only around 0.1% error.

What is critical is the quality of impact on the board end. Dynalyse look for a crosscut within +/- 5mm tolerance to give the best opportunity for the stress wave propagation. Mis-impacts can also occur due to boards with severe wane, twist or bow on the near end. In these cases, if the signal quality is not above a defined threshold the board is graded as reject.

Background noise is considered during installation of the system. The type of noise encountered tends to be random and therefore rarely causes problems to the grading modulus measurement. Dynalyse recommend a basic sound 'survey' with potential outcomes including:

- Fitting covers to nearby saw blades to control the sound path
- Dampening any resonant vibration sources – for example filling nearby rollers with sand.

6.1.4. Design Considerations

The Dynagrade is currently only designed for dry, planed timber. The company have done tests on green lumber but feel that more energy is required in the hammer impact to ensure signal quality. This necessitates further research into optimal setup along with the associated hardware and software changes.

The system includes two microphones for detecting the frequency of the stress wave in the timber. As well as providing a means of ensuring good signal quality in the measurement of longitudinal vibration, the setup also means the system is flexible enough to grade various board widths and thicknesses continuously – without a hardware 'size change'.

A modem is installed in every system to allow Dynalyse remote access for servicing, upgrades and troubleshooting.

6.1.5. Quality Control

According to the current European standard EN519, machine control is the primary means of assuring the quality of strength graded material. With the majority of Dynagrades installed in Europe, stringent testing has been completed on various local species to derive a standard set of machine settings by which operators work to. Dynagrade machines have different acoustic velocity settings for different species and different moisture contents.

Daily machine calibration includes an accuracy test where a special LVL calibration beam is measured. The software compares the results of the test to the archived data for the beam and delivers a pass or fail. If the calibration fails, then the sensors must be checked to ensure there is no error in the length measurement or issue with signal quality from the microphones.

The control system has a number of alarm events that can be programmed to assist operators in quality issues during normal production. An example is to trigger an alarm when a certain number of consecutive 'reject' boards are recorded. This could indicate that a sensor fault is delivering poor signal quality – and therefore causing the downgrade.

6.1.6. Perceived Benefits

Dynalyse believe the primary benefits of the Dynagrade include:

- Relatively high production speed capability of 100 lugs/minute
- Simple yet reliable and very repeatable grading modulus, regardless of board orientation. As an example of the repeatability, Dynagrade personnel have retested a sample board four years after the initial measurement and seen only a 1% variation.
- Ease of installation and ease of use. The Dynagrade does not require a specific operator, with traditional visual graders more than capable of managing the day-to-day operation.
- Relatively low maintenance compared to bending-type 'traditional' stress graders – the Dynagrade has few moving parts and a simplistic measurement action that does not involve high forces (eg. bending). The most exposed components include the microphone housing (given its proximity to the moving boards) and general wearing of the belts.
- Startup times are very quick given that no hardware or software reset is required for size changes. This is critical for producers that split boards in the planer asymmetrically, producing various widths during a single shift.
- Cost competitiveness.

6.1.7. Relevance To Radiata

Dynagrade installations have primarily been limited to European countries processing local species such as Norway Spruce and Scots Pine. Significant testing has been completed to prove that the grading modulus works well to sort the timber into the relevant stress grades. In fact, the discussion above highlighted that the system works surprising well in terms of correlation to not just stiffness but tensile strength and knot area ratio. With these species, the knots are relatively uniform in size and spacing.

In 2000 a grading trial was completed on a sample of radiate pine for a NZ producer. At the time there was confirmation that the MoE values derived by the system were 'representative' of New Zealand graded material.

6.1.8. Mill Visit – Derome Timber AB (Derome Sawmill).

OVERVIEW

The Derome sawmill located in the municipality of Varberg, Sweden, installed a Dynagrade around 2002. The company is a third generation family owned business with around 250 personnel at the Derome sawmill alone – the Derome Group manages a number of businesses from forestry through to the finished home.

PRODUCTION SETUP

The Derome sawmill produces around 160,000m^3 sawn timber output per annum. Around 75% of this output is C24 machine stress graded (MSR) lumber, with the remainder recovered for visual graded structural material (studs etc). Timber lengths between 3.0-5.4m are produced with finished sizes around 70x45mm (exact dimensions vary depending on end market). Approximately half of the output is destined for the UK market.

All feedstock is spruce, coming from private forests in southern Sweden and a small proportion from Russia.

The Dynagrade replaced an offline Computermatic stress grader. It is installed just downstream of the planer, which is capable of running at up to 250m/min. The boards exit the planer onto a slowdown belt before being loaded into lugs and fair ended in preparation for measurement. The lug rate varies from 30-50 lugs/min.

The Dynagrade and its main unit with PC monitor are located adjacent to a visual grader. The grader sits in an elevated position such that they can easily see the monitor, thereby allowing constant verification of grade recovery (via the bar charts), which is a good indicator that the process is 'in control'. The main grade-limiting external characteristics (that the visual grader is confirming) include blue stain, rot, wane and checks. See Figure 18 for an example of 'typical' finished product.

The visual grader's decision is combined with that of the Dynagrade and the control system initiates appropriate roller branding of each piece. Two horizontal bin buffers 'Grade' and 'Reject' are downstream to facilitate sorting prior to stacking.

QUALITY CONTROL

The Dynagrade runs on fixed machine control settings for spruce – as per EN519. Once per shift the LVL control beam is used to confirm measurement accuracy. The mill's visual graders and tool sharpeners are responsible for the QC and general day-to-day running of the system.

PERCEIVED BENEFITS

The primary benefit of the Dynagrade according to mill personnel is simply lower production costs. The system replaced an offline Computermatic system. Now they have the ability to grade MSR inline and at a faster production rate.

Fig. 18: Spruce graded by the Dynagrade at Derome sawmill – note small knot size

KEY ISSUES

The only issue Derome have encountered was controlling the reaction to the hammer blows. With short pieces, they were finding that the impact was sufficient to shift the board itself. In response, a wheel located on an overhead arm at the hammer point now provides enough downward pressure to resolve this.

6.2. Microtec - ViScan

6.2.1. History

Microtec was formed in 1980 as a technology provider for the wood processing industry. The company employees over 100 people and is based in Brixen, Italy – with branches in Linz, Austria and Metre, near Venice.

The company specialises in optical scanning, with one of its first successes being a laser-cutting technique for 3D surface profiling in 1985. This was followed up in 1992 with vision scanning technology for detection of surface faults and the introduction of x-ray imaging in 1994 to augment knot recognition. Microtec also developed a tracheid effect sensor in 1997 and introduced a system for strength sorting based on x-ray and neural networks in 1999.

A 'full visit' to Microtec was not possible during the research trip. Instead, general information was gathered on the Mcrotec ViScan and Goldeneye systems during discussions with Microtec personnel at Ligna+ (Tradeshow, Hanover). Additional information has been sourced from Microtec's website.

6.2.2. Machine Description

The ViScan system is only around 6 months old, and the company has 7 installations to date. It is relatively similar in overall look to the Dynalyse Dynagrade and also shares general board handling methods – but the significant difference is in how the system measures acoustic velocity. At one end of a set of transverse speed-up belts is the main unit, consisting of impact hammer and laser interferometer. At the other end is a 'light shadow' sensor for measuring board length. The entire system is less than 2m in length and accommodates boards of length up to 6m and cross section 20-120mm thickness by 80-280mm width. Maximum feedspeed is 150 lugs/min. Refer to Figure 19 for a depiction of the ViScan main unit.

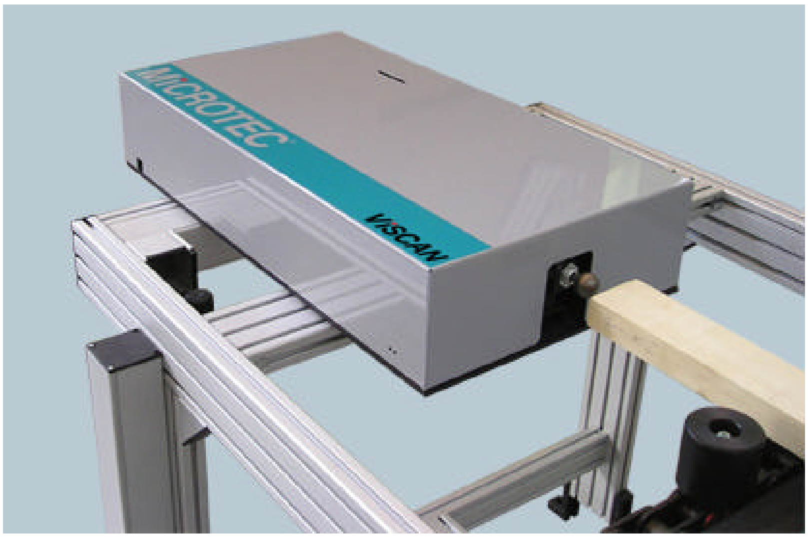


Fig. 19: Microtec ViScan (courtesy Microtec website)

Boards approach the machine in transverse lugs, with the speed-up belt facilitating isolation and raising of each board into the lug space immediately prior to impact from the hammer. As with the Dynagrade, the hammer initiates a longitudinal stress wave in the wood – but instead of relying on microphones for measurement of vibration frequency, the ViScan's laser interferometer is able to record the time-based response of the vibration. It then converts this into the frequency domain to get natural frequency and finally an acoustic velocity for the board.

6.2.3. Grading Modulus

The ViScan system uses the measurement of natural frequency and board length to calculate acoustic velocity. Laser triangulation is typically not needed for length measurement – instead an array of infrared transmitters and receivers is setup to look for a 'light shadow'. This provides the basis for sorting material into stiffness grades. Microtec claim that the measurement of this indicating parameter is extremely repeatable – with a coefficient of variation of less than 0.5% on multiple measurements for the same sample (Giudiceandrea, 2005).

They also believe that the laser doppler effect used (via laser interferometer) is very accurate and insensitive to ambient noise.

The ViScan can be integrated into other Microtec systems (such as the Goldeneye – see Section 8.4). In this application the Goldeneye provides a measurement of board density using x-ray scanning, and coupled with the ViScan's acoustic velocity indicator, the grading system can deliver dynamic modulus of elasticity.

6.2.4. Perceived Benefits

The perceived benefits of the ViScan are similar to the Dynagrade Dynalyse – one of them being the relative simplicity of the measurement process and associated reduction in maintenance costs compared to 'traditional' mechanical stress grading machines. This simplicity also makes retrofitting of the ViScan very easy.

In terms of method of measurement, Microtec believe the laser doppler effect has advantages over microphone sensors due to its insensitivity to environmental conditions.

6.2.5. Relevance To Radiata

Microtec have not applied the ViScan for sorting radiata timber, but do not feel that the species will pose any unique challenges. The company is confident that significant characteristics in radiata such as knots, slope of grain and other fibre disturbances have enough impact on the vibration path to effect the grading modulus. Hence, the system should provide a robust means of sorting into MGP stress grades. Interestingly, a number of Microtec's European customers are considering using the ViScan (in combination with the Goldeneye) for sorting spruce into MGP grades for export to the Australian and New Zealand market.

7. GROUP (3) – MEASURE EXTERNAL CHARACTERISTICS

7.1. Autolog – Linear Planer Optimiser (With Visual Defect Detector)

7.1.1. History

Autolog is based in Blainville, Quebec. The company started operation in 1987 when its 3 owners all moved from one industry service provider to join forces and begin marketing bin sorter control and tally equipment. Each owner is recognised for their respective expertise in research & development/optimisation, control logic and sales management, while the company as a whole aims to be a leader in innovation. The company remains focused on the timber industry, and is currently in a state of expansion – with 57 people 3 years ago now reaching 104 today. Autolog have sales and service personel in British Columbia and southern US.

During the 1990's Autolog developed a number of sawmill optimisers – including the edger optimiser, transverse cant optimiser and trim optimiser. In 1998 it released the Linear Planer Optimiser, followed by the Visual Defect Detector add-on in 2004. All of Autolog's scanning systems use similar sensor technology coupled to internally developed software and construction - meaning the company has significant experience in scanning and optimising generally.

There are currently 62 Linear Planer Optimiser (LPO) installations along with 11 Visual Defect Detectors (VDD - approximately 6 still to be installed). Interestingly, Autolog have a performance-based agreement with their biggest customer – Canfor – to deliver grading solutions which will require no visual overrides by the year 2007 (ie. 'graderless' grading). Canfor currently have 11 LPOs in operation.

7.1.2. <u>Machine Description</u>

The LPO is designed for linear board flow and can be directly coupled to a planer. The VDD is designed as a 'bolt-on' to the LPO frame and effectively just adds another scanning focus point to the machine. Overall, with both LPO & VDD, the system is just over 4m in length (see Figure 20 for a photo of an installed machine).

The machine accepts boards of length 1.8 – 7.3m, with a range of widths being 63.5 – 304.8mm and thickness up to 101.6mm. Maximum production speed is 600m/min (2000 ft/min), with the LPO (not the VDD) being the limitation currently.

Fig. 20: Autolog LPO (Bowater mill)

The measurement process is as follows:

- The timber flows into the LPO section linearly with press roller taking control of speed.
- Photoeyes and encoders allow for registration of scanned data.
- Four laser triangulation scanners target each face and measure the board geometry.
- Outfeed rollers maintain control of each board as it flows into the VDD – directly bolted onto the end of the LPO
- The LPO, as part of its geometric assessment, uses the relationship between the clamping forces of the press rollers to predict twist and bow.
- In the VDD four black and white cameras target each face to measure light contrasts along the board as part of characteristic detection.
- Illumination for the VDD is provided by four banks of blue LEDs mounted diagonally to each face
- Immediately after leaving the VDD each board is sprayed with 3 identical binary codes along a section of its trailing end (typically bottom face). This is achieved with a UV printer for the purposes of board tracking (see Figure 21 for an example of a binary code).
- In typical applications the flow of timber then moves into transverse lugs downstream, past visual graders and then into a trimsaw for final cut solution prior to binsorting. An Autolog UV reader is mounted prior to the trimsaw to identify specific boards and re-match their cut solution.

Product thickness changes are initiated by raising the overhead press rollers using pneumatic cylinders (see Figure 22). Spacer blocks of various thicknesses are then inserted to locate the upper frame. Width changes are completed by cranking the sensor frame in and out such that the lasers remain central to each face.

Fig. 21: Illumination of UV binary code (Claude Forget Inc mill)

The system employs a total of 5 PCs to drive the optimisation, allowing a board solution within around 0.5 seconds of scanning. Specific PC roles:

- ‘Concentrator’ PC mounted at the scanner for receiving sensor data
- ‘Optimiser’ PC for developing optimised board solutions
- UV reader PC
- Control PC
- User interface PC

Fig. 22: Autolog LPO – outfeed press rollers & pneumatics for size change (Claude Forget Inc mill)

The Autolog software is based on an SQL database. Its user interface includes a black and white image of every board as it is scanned – in 2-dimension and 3-dimension. Specific biological characteristics and geometric characteristics are classified and highlighted on the image. The system provides a 1000 board buffer to allow for board flow from the scanner to trimsaw, while there is a 100 board on-screen buffer allowing the user to analyse a recent board solution in full. A full suite of configurable reports are available that summarise recovery performance.

The software also includes a realtime simulator that allows the user to re-run real production data to assess the effects of potential grading rule changes. All systems include a modem to allow remote dialup support.

7.1.3. Grading Modulus

The LPO measures board width and thickness with an accuracy of +/- 0.254mm. The scan resolution along the board is 12.7mm. Within the accuracy of this measurement, the system classifies the following geometric characteristics:

- Cross sectional size
- Wane
- Skip
- Twist – predicted based on clamping forces
- Bow – predicted based on clamping forces

Although the warp measurements are predicted, Autolog have not had to augment this measurement with the installation of a separate warp sensor downstream.

The VDD develops a black and white contrast map along each face of the board. It is designed to classify knots primarily, but can also detect splits. The scanner resolution is 0.635mm, allowing knots as small as 6.35mm (size – measured using displacement method) to be measured. The system uses National Lumber Grades Authority (NLGA) rules to define the size and type of knot – either centre or edge. As part of the classification, the optimiser must predict the knot location relative to pith. It achieves this by assessing data such as the existence of wane on the board, or edge grain patterns – replicating the logic that a visual grader uses instinctively.

Via the software interface, the user defines grade limits for both the geometric and biological characteristic classifications. The resulting optimised trim solution is always based on grade value.

The LPO & VDD is currently not designed to completely replace visual graders. In terms of visual characteristics, the system is not presently capable of classifying the following:

- Rot
- Slope of grain
- Stain
- Bore holes

The system can also accept data streams from other measurement equipment, including online moisture meters and Metriguard HCLT stress graders. These board profiles are integrated into the final grading solution, and can be very powerful additions for cut-in-two solutions (eg. 2 different stress grade pieces produced out of a single input).

As discussed in the Section 4.1.4, effective scanning technology is dependent not only on accurate measurement, but also accurate classification of characteristics. Autolog spend time to 'tune' their knot measurement by adjusting factors such as knot boundaries. (ie. Where on the outer rings of a knot do you define the actual boundary of that knot? This will vary from species to species). In specific board trials, Autolog have been able to correlate predicted versus measured knot size to within 3.175mm error (average) – this error can drop to 1.6mm for centre knots.

Autolog guarantee to deliver grade recoveries with less than 4% material overgraded and less than 8% undergraded during client acceptance testing. Autolog believe that visual graders typically deliver around 20% overgraded and 40% undergraded in comparison.

Another performance test delivered the following results:

- 200 boards of southern yellow pine were selected. Characteristics visually measured then compared to Autolog output.
- Optimiser delivered over 90% grade accuracy compared to 60% for visual graders
- When cut-in-two solutions compared, grader accuracy dropped to around 40%
- Trim loss marginally reduced using the optimiser – around 1%
- Value yield increased by $20/1000 bf using the optimiser
- Less than 10% of characteristics were not capable of being classified by the optimiser – these represent the characteristics that remaining visual graders would have to concentrate on during operation of the machine (all other decisions are better made by the optimiser).

7.1.4. Design Considerations

Two relevant design considerations were noted during the visit to Autolog. The first is the decision to use LEDs as a light source for the VDD camera scanning (others typically use halogen). Autolog went this way due to a number of factors:

- The blue LED light provided the best contrast for knot detection on southern yellow pine – which was the species that the machine was initially designed for
- The LEDs provide better light efficiency – do not 'burn'
- Durability
- Consistency of light
- Smaller size – easier to integrate into frame

Another aspect of the Autolog design is the use of the internally-developed UV printer and reader.

Up until 2 years ago, LPO systems employed Domino-type printers but the company found that the printers were susceptible to the dusty mill environment and demanded significant operator knowledge to run and keep calibrated. The ink was also sensitive to temperature, and proved ineffective on frozen boards. To overcome these reliability concerns, the UV printer was designed (Fig. 23). The company now feels that board tracking is no longer a reliability issue.

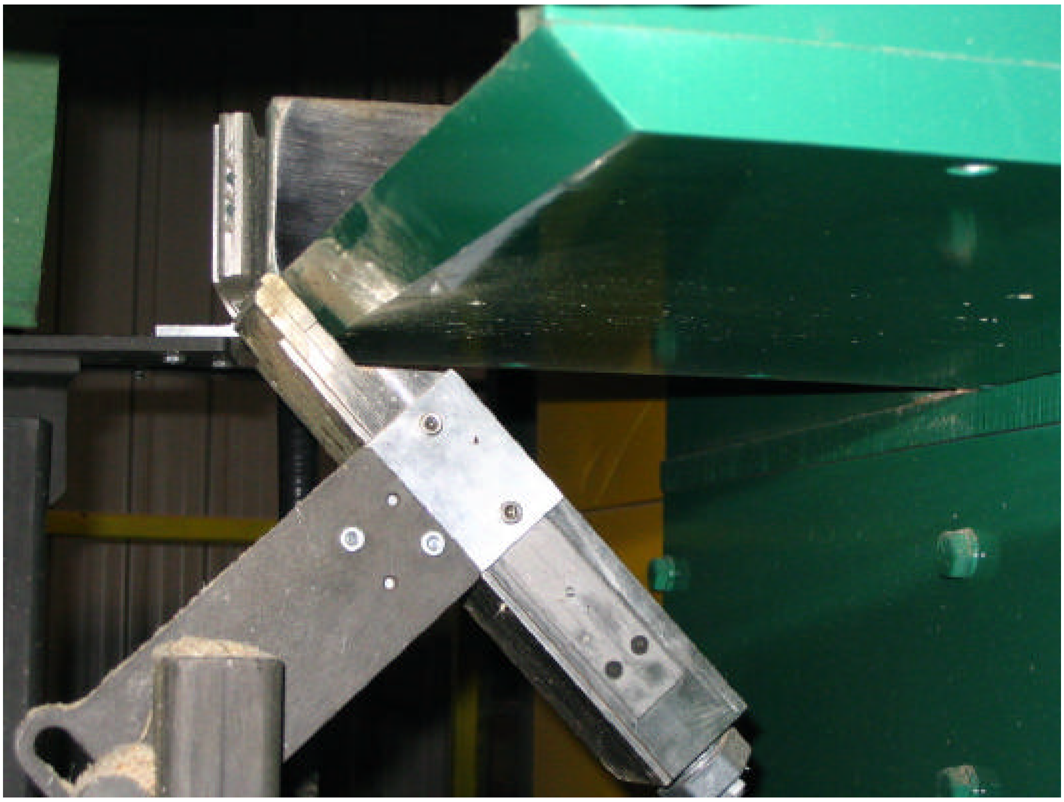


Fig. 23: Autolog UV printer (Claude Forget Inc mill)

In terms of future developments, Autolog follow a stepwise, modular approach to design. The company believes in strongly linking customer requirements to design priorities. As an example, the emphasis on knot classification in the VDD came about to due southern yellow pine producers (located in southeast US) – whose main grading issues are knots. Canadian fir and spruce processors, in comparison, are not as concerned about knots.

Future developments include:

- Rot detection sensor – Autolog are already working on a sensor that uses wave absorption characteristics to measure rot
- Improving geometric measurement accuracy and resolution at faster speeds – the company is aiming for a 10x improvement in measurement accuracy (+/- 0.0254mm) with 2x resolution improvement (down to 6.35mm) at 900m/min
- Hardwood industry solutions – different needs base

7.1.5. Quality Control

Autolog recommend a sensor calibration once per week for the LPO. The check involves the use of an aluminium bar to confirm the accuracy of the laser profile measurements. The company is very aware of possible temperature effects on laser calibration. The LPO selects in real-time the best calibration 'lookup' table according to ambient temperature – hence temperature compensation is automatic.

The machine itself incorporates several elements designed to assist in maintaining product quality during production. These include:

- Air sprays on the bottom laser head – designed to keep the lower sensor free of debris and dust. Autolog also recommend manual cleaning of the feed rollers to prevent resin buildup
- Software functionality to automate the sampling of 'QC boards'. Here the operator can choose to sort boards at a defined frequency from a specific grader, and within a specific grade to allow offline checks on the overall grading process.

7.1.6. Perceived Benefits

Autolog see the primary benefits of the LPO and VDD are:

- Grading accuracy – performance testing sometimes highlights grade lift into premium products that visual graders never recover during production. Associated with this is the observation that visual graders will remain conservative. For example, if there is slight wane on a board, a visual grader will tend to downgrade given the limited time to accurately assess the extent of the wane.
- Grading consistency
- Increased throughput – faster production speeds
- Increased value yield – in a mill that produces 200 million bf/annum, then the average $20/1000 bf increase in yield represents a $1million annual benefit

As a company, Autolog believe they can deliver the benefit of having been in the scanning industry for a long time – in fact having the very first planer mill optimiser installation. The company maintains a focus on continuous improvement and R&D, and asserts that customer feedback highlights a better reliability and consistency in performance compared to competitor products.

7.1.7. Relevance To Radiata

The VDD was designed to work with southern yellow pine initially – and the discussion above highlights a number of design considerations specific to processing this species. This is important, given that physically, radiata is similar to southern yellow pine – in terms of colour, knot size and shape. Autolog have also had the opportunity to trial Australian radiata and feel that the system performs well with the species.

7.1.8. Mill Visit – Claude Forget Inc

OVERVIEW

The Claude Forget sawmill is located in Laurentide, Quebec. The mill itself is very new, with all operations being relocated from an old site 1 year ago. As part of the new mill, an Autolog LPO (no VDD) was installed in the planer mill alongside visual graders.

PRODUCTION SETUP

The mill processes fir and spruce in lengths up to 4.8m and cross sections 2x3 – 2x6. All material is visually graded for dimension lumber. The planer mill is currently operating at around 540m/min (105 lugs/min) but this represents only 50% of the eventual target production mark.

The LPO is close coupled to the planer, with a face and edge UV printer designed to maximise board tracking reliability. After a slowdown belt, the boards enter lugs and pass under a UV reader to be re-identified and matched to their machine solution. A spray marker is immediately downstream of the reader and sprays the ends of boards where 'no decision' can be found – potentially due to inability to recognise UV code or due to the optimiser not able to find a solution. This signifies that the visual graders must grade for all characteristics.

There are three visual graders who have separate, well designed and well lit stations where they control final grade decision via a button console. The graders are only looking for characteristics that the LPO is incapable of grading (refer to Figure 24 for a layout photo of a grading station).

Fig. 24: Grading station - Claude Forget Inc mill

After the visual graders there are two trim saws for cut-in-two solutions and finally a binsorter.

QUALITY CONTROL

The mill produces visually graded lumber in accordance with the Quebec Forest Industry Council (QFIC). This necessitates regular pack checks to ensure grade accuracy.

The grading agency was also present during commissioning of the LPO – with tests conducted to confirm the machine's capability to grade accurately.

The QC Manager and Shift Supervisor are responsible for the operation of the LPO. Routine tasks include:

- Weekly calibration check in accordance with Autolog recommendations (2 minute task)
- Checks to confirm measurement accuracy during shifts where big ambient temperature swings occur
- General cleaning of the machine during shift breaks – ensure it remains free of debris.

The Autolog user interface is located in the supervisor control room behind the visual graders. There the supervisor uses shift reports and onscreen board solutions as reassurance of machine control. The visual graders have an 'infomaster' display in front of them to allow basic reporting on machine condition.

PERCEIVED BENEFITS

Claude Forget personnel reinforce that accuracy and consistency are the major benefits of the LPO: "the machine never sleeps!". The system has also allowed production speed to increase by a factor of three, while graders now have a much easier job (tighter focus), and have readily accepted the system. The mill Shift Supervisor confirmed that the graders only initiate a visual override on around 1 in 10 boards – these representing the boards where the LPO is not capable of classifying all the characteristics.

KEY ISSUES

The Shift Supervisor only mentioned two specific issues in the operation of the LPO:

- Rot on board ends – this can interfere with the UV code and cause a 'no decision' board (see Figure 25 for an example of this problem).
- Debris in the scanner – this blocks the sensors and tends to produce a 'no decision' in the grading logic.

Fig. 25: Rot on board ends – issue for UV reader

Another interesting point, which is not an issue as such, is that customers were initially unhappy with the product they were receiving from the mill. This represented an effect of the precise nature of the grading process. Historically visual graders had been conservative in terms of wane etc whereas the LPO ensures consistent, concise decisions with very little grade falldown. This has become less of an issue as clients have got used to the product and as more producers also implement scanners.

7.1.9. <u>Mill Visit – Bowater</u>

OVERVIEW

Bowater sawmill is located in Maniwaki, Quebec. The line has been running for one year and, like Claude Forget, the mill has installed an LPO system.

PRODUCTION SETUP

Bowater produce visually graded dimension lumber from a spruce and fir mix. The range of product lengths varies between 3.0 – 4.8m, with sizes 2x4 – 2x8 (dry) and 2x4 – 2x6 (wet). Production is currently at around 100 million bf/annum, equating to around 75 lugs/min line speed.

The machine layout is very similar to Claude Forget, except that Bowater require only two graders. Their focus is on rot, split, internal checks and knot size – with rot being the key issue with fir. The line also incorporates an online moisture meter downstream of the graders. The optimiser decision is compared to the visual grader decision, giving the ability for the visual grader to downgrade a board based on the characteristics noted above. The moisture meter input represents the final factor in assigning the grade. Bowater also use the autostacker operator as a 'backup' grade checker.

QUALITY CONTROL

The QC Supervisor is responsible for the operation of the LPO. Bowater material is graded in accordance with QFIC (as per Claude Forget). Output checks and routine machine checks are very similar on the two lines.

One point of interest in this case was that QFIC were present during startup – but also required input into appropriate grade rules for the optimiser. Bowater personnel commented that the difficulty here is that QFIC are relatively inexperienced with this technology, and don't exactly know how to deal with the machines from an audit position.

In terms of maintaining machine control, the QC Supervisor at Bowater carries out the following ongoing tasks:

- Alarm monitoring – including consecutive 'undersize' and 'no decision' boards. These may represent errors in the measurement calibration or debris within the machine
- Shift reporting – including shift to shift comparisons of throughput, grade recovery and trim loss. These reports provide a monitor for overall system 'health'.

PERCEIVED BENEFITS

Bowater personnel see the following as key benefits of the LPO:

- Product consistency
- Measurement accuracy – this is reinforced given the historical problem in visual grading when boards were not adequately turned, leading to edge characteristics escaping attention.
- Process productivity and overall yield
- UV printer reliability – Bowater no longer have problems with code recognition, especially on frozen boards.

7.2. Coe Newnes/McGehee – D*TEC 5000 BioScan

7.2.1. History

The Coe Group is a provider of technological solutions for the forest products industry. The group has very diverse origins, starting in 1852 with the Coe Manufacturing company setup in Paineville, Ohio by Harold Coe and Leonard Anderson. Critical to the company's longterm success was the development of the first rotary veneer lathe in the early 1900s. Around the same time (1912), William Newnes developed a small blacksmith shop in Salmon Arm, BC. This company grew into sawmill equipment supply, eventually specialising in electronic controls and optimisation. In 1996 Newnes entered into a joint venture with McGehee equipment, delivering – among many products – cant curve saws, linear edgers and planermill optimisers. Coe Manufacturing acquired Newnes/McGehee in 2002 to form the Coe Group.

Coe Newnes/McGehee (CNM) is part of this group, and specialises in lumber handling equipment throughout the sawmill and planermill, machine control, along with scanning and optimisation. Around 250 people work at their Tigard, OR base, which looks after the manufacture, project management, engineering support and ongoing development of the D*TEC BioScan system.

The development of the D*TEC BioScan can be traced back to the 1980s, when Saab Systems began offering sawmill trimmer and edger optimiser systems. Saab Systems was acquired by Coe Manufacturing in 1985. This coincided with the company beginning significant R&D effort into visual surface grading. CNM believe there is at least 100,000 manhours of software and hardware development behind their D*TEC BioScan technology, culminating in the first planermill system implementation in 2003.

There is currently 15 geometric-only D*TEC systems installed together with a further 5 D*TEC BioScan systems (geometric and biological scanning).

7.2.2. Machine Description

The D*TEC BioScan system is designed for transverse timber flow. The system can accommodate timber up to 7.3m in length with cross sections up to 101.6 by 304.8mm. The scanner frame sits above the timber line and is around 1.7m in length. Maximum production speed is 160 pieces/min up to 250 pieces/min for stud material. Refer to Figure 26 for an overview photo of the scanner frame.

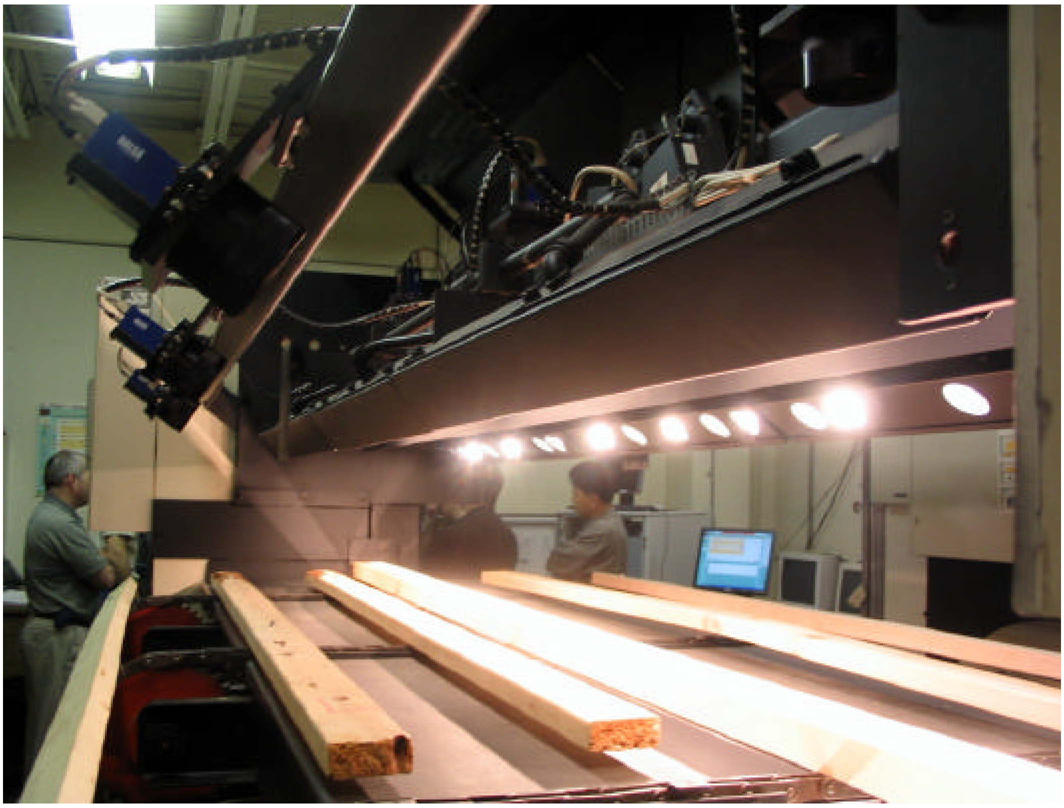


*Fig. 26: D*TEC BioScan scanner frame (COE Newnes/McGehee Tigard lab)*

The measurement process is as follows:

- The boards are loaded into lugs and fair-ended upstream of the machine
- Immediately prior to the machine, the lug chains are terminated with control handed over to a narrow aspect timing belt. This belt has a rough surface that enables the board to flow under the scanning frame in a 'virtual' lug space with the four faces exposed in the scan envelope.
- Multiple pairs of lasers and high-resolution digital black & white cameras are mounted directly above and below the scan envelope, with further pairs mounted diagonally above angled toward the front and rear edges.
- Halogen lamps mounted diagonally in-front and behind illuminate the four faces (see Figure 27 for schematic drawing).
- The lasers scan the four faces for geometric characteristics while the cameras, with the help of the illumination, provide contrast scanning for visual characteristics (primarily biological – such as knots etc).
- Once scanned, board control is handed back to a normal chain lug system prior to a trimmer. The grading solution for each board is achieved within one lug space timing – meaning that the trimmer can be located very close.
- In typical applications a grader and grade mark reader are placed upstream of the scanner, allowing the scan solution to be appended to operator input for the final trim decision

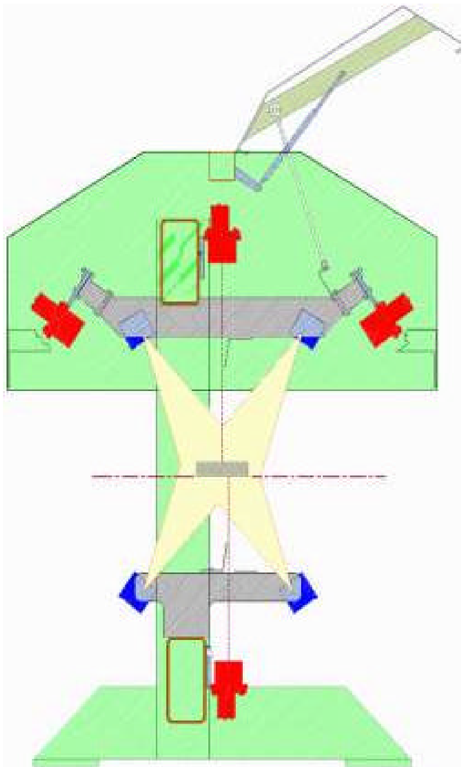


*Fig. 27: D*TEC BioScan scanner frame schematic – laser & cameras highlighted in red, halogen light sources in blue (courtesy: Coe Newnes/McGehee)*

The D*TEC BioScan uses proprietary image pre-processors and VME-based computer architecture to ensure high speed analysis and optimising. This means that the characteristic classification 'intelligence' is combined into software and hardware.

The software interface includes real-time 3D colour images of each board (all four sides), with characteristics highlighted to allow easy visual assessment of grade decisions. Shift summary information is also within easy reach, and includes volume throughput, grade recovery and trim loss data. The user can compare production from recent shifts as well as run grade rule 'what if' scenarios using saved board data.

7.2.3. Grading Modulus

The D*TEC BioScan provides optimisation of the following geometric characteristics:

- Cross sectional size
- Wane and end contour
- Skip
- Warp – bow, spring, twist
- Voids on ends

The laser scan resolution along the board length varies between 50.8 to 76.2mm and between 25.4 to 38.1mm across the width. The accuracy of the respective dimensions are:

- Thickness +/-0.254mm
- Width +/-0.508mm
- Length +/-2.032mm
- Warp +/-1.016mm

The black&white scanning system provides optimisation of the following biological characteristics:

- Knots and holes – using the displacement method of sizing. To accurately size knots, the optimiser aims to predict the location of the pith relative to the board. This is done by acknowledging the presence of spike knots, wane (which side? how much?) and the general size of the knots on the board.
- Shake, split, check
- Stain – no differentiation between blue and brown
- Bark and resin pockets
- Prescence and location of pith
- Worm/grub holes

The image resolution is 0.635 x 0.635mm with a claimed knot size accuracy of +/-1.27mm and split size accuracy of +/-0.381mm. With this resolution, there is around 20MB of data delivered for processing by each board. Refer to Figure 28 for an example of a characteristic 'extraction'.

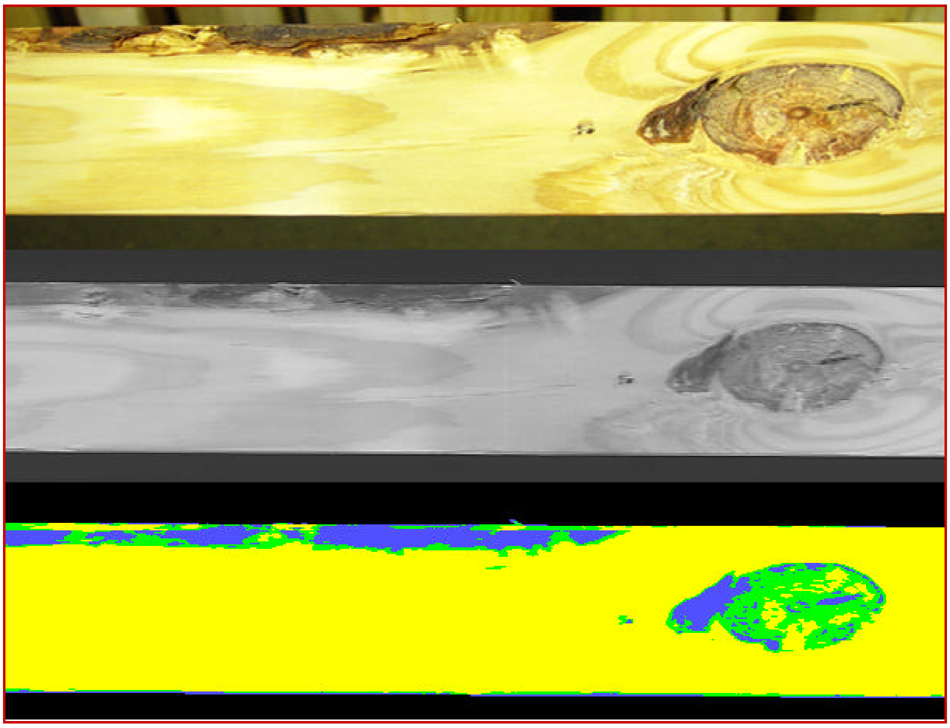


*Fig. 28: D*TEC BioScan characteristic 'extraction' – photo of knot & wane, black & white image, characteristics identified for classifying (courtesy: COE Newnes/McGehee)*

As with the Autolog, the D*TEC is currently not designed to completely replace visual graders. The system is not presently capable (or has difficulty with) classifying the following:

- Slope of grain
- Blonde knots – due to the lack of contrast the scanner has difficulty sizing these type of knots.

- White speck fungus
- Blue stain vs. brown stain – the scanner cannot distinguish between given colour limitations.

In terms of grade decision integration, the system can augment visual grader input via a grade mark reader, and stress grader input using a separate colour camera focusing on the board end to 'look' for grade spray marks. This obviously limits the integration to one grade per board.

CNM state 95% or better on-grade measurement performance from the D*TEC BioScan. Further evidence of the accuracy of the system can be found in an independent article detailing a recent installation at the Roseburg Forest Products stud mill. This quotes the mill manager, Marc Mendenhall, as saying "the grading system has maintained a more than 97% on-grade track record since it started up" (Timber Processing, 2005). In this installation a single grader remains to augment grade decisions where the scanner is limited in its ability to classify (eg. blonde knots). The article quotes the quality control supervisor, Dave Reader, who believes the install has "greatly reduced the graders' workload, allowing them to concentrate on a few defects instead of a brain-full of grading rules".

*7.2.4. **Design Considerations***

CNM have developed the D*TEC BioScan to ensure significant grading characteristics are accurately measured and classified. For example, they view wane as the most relevant 'down-grading' feature and have therefore aimed to deliver a system with the best wane measurement capabilities of all transverse machines. Face knots, spike and unsound edge are all considered frequent occurrences along with bark pockets, split and shakes, and pith.

In comparison, CNM see the difficult-to-classify blonde spike knots as occurring less than 5% of the time, while grain distortion, worm holes and white speck fungus as even less frequent.

Three aspects of the D*TEC BioScan design were discussed with CNM personnel. The first relates to the black & white cameras. CNM have decided to employ black & white over colour cameras because they believe the benefits of enhanced resolution in black & white outweigh the modest advantage in being able to distinguish the colour of characteristics on the wood surface. Furthermore, colour scanning requires significantly more processing power and is not considered the most suitable and simplest means to progress the D*TEC product.

The second aspect of the D*TEC design is the attention paid to appropriate illumination. CNM have worked hard to ensure a consistent light source from the halogen lamps. This improves the contrasting between parent wood and characteristic needed to reliability and accurately classify.

The third aspect is the move to image pre-processing hardware and VME-based optimising. CNM have developed this approach to maximise data processing speed. Unlike other machines, this approach will sometimes necessitate both hardware and software upgrades in the event that the characteristic classifying logic is revised (eg. when new wood characteristics are added to the capability list).

In terms of future product development, CNM are striving for ‘graderless grading’. Specific development objectives include:

- Enhanced resolution in cross section profiling

- Ongoing refinement of characteristic classification (ie. "how you gather the data and what decisions you make with it")
- Enhanced image processing capability
- Improvements in illumination – possibly including a switch to LED illumination
- 'Data Fusion' – this concept is one that is shared with CNM's LHG machine. It relates to the introduction of sensors such as laser dot, laser scatter and multi-spectral vision to enhance the classification of characteristics including slope of grain, grain distortion, knot sizing and differentiation of stain.

7.2.5. Quality Control

CNM recommend a number of measures and checks to ensure product quality during production. The minimum maintenance activities include:

- Physical cleaning of cameras and laser sensors (twice/shift)
- Auto scanner calibration check (weekly) – involves a simple check of laser profiling accuracy and light intensity levels
- Full scanner calibration (monthly) – represents a 10-15min exercise
- Lamp bulb replacement and scanner alignment (semi-annual)

Typical installations see a software interface installed in the production control room rather than directly at the grading station. Operators rely on the real-time reporting of recovery, trim loss and size distributions as means of providing confidence that the machine is in-control. The software allows alarm levels to be setup to flag the occurrence of excess trim – which may indicate a malfunctioning or obstructed sensor.

7.2.6. Perceived Benefits

CNM believe the primary benefits of the D*TEC BioScan are:

- Accuracy and consistency in grading – meaning less overgrade/undergrade
- Increased grade recovery and value realisation
- Accurate cut-in-two solutions based on visual characteristics
- Reduced operating costs - derived from:
    - less trim loss (ie. less waste)
    - reduced labour requirements – typical installations see no more than 1 grader required (who has less rules to concentrate on, and can therefore work more effectively)
    - reduced risk of worker's compensation claims due to the manual labour aspect of grading

To reinforce these benefits, CNM provide a summary of a recent installation:

- 95% or better on-grade (with only 3-8% visual grader input)
- 4% increase in value realisation
- 3% reduction in waste
- 66% labour saving (3 graders/shift down to 1/shift)
- 9 month return on investment – CNM quote a better-than 1 year ROI (assuming 125mmbf annual production).

CNM believe that the unique value proposition for the D*TEC BioScan product is derived from four aspects:

1. The advantage of a long association with scanning technology development – dating back some 25 years.
2. Superior characteristic detection and classification
3. Superior wane measurement compared to other transverse machines
4. Commitment to service

7.2.7. Relevance To Radiata

To date the D*TEC BioScan has not been employed to grade radiata. CNM confirm that they have successfully trialled the species in a laboratory setting (see Figure 29 for depiction of Tigard laboratory samples). This is also the case for southern yellow pine. Species being processed in production applications include:

- Douglas fir
- Western hemlock
- Hem-fir
- Spruce
- Lodgepole pine
- Ponderosa pine
- Spruce-Pine-Fir

Fig. 29: Trial boards of various species in Coe Newnes/McGehee Tigard lab

7.2.8. Mill Visit – Stimson Lumber Company

OVERVIEW

The Stimson Lumber Company mill is located in Forest Grove, OR. The mill produces some 124 separate products, including studs and dimensional lumber. The mill have installed a D*TEC BioScan on their stud line, which produces mill-specific stud products.

PRODUCTION SETUP

The stud line processes a mixture of green douglas fir and kiln-dried hemlock, in cross sections 2x4 and 2x6. Production capability is around 11-12mmbf/month – equating to approximately 120 lugs/min.

Material passes through the planer and online moisture meter prior to a slowdown belt and transverse chain. A single visual grader is located at this point, and is tasked with identifying and grading the following specific characteristics:

- Slope of grain
- Timber break
- Manufacturing characteristics
- Decay – typically the same colour as the clearwood.

Stimson Lumber personnel confirmed that the grader is responsible for only around 5% of all grade decisions, with the D*TEC handling the majority of classification.

Downstream of the grader, the boards are fair-ended and loaded into lugs. A grade mark reader is situated at the lug loader. The boards are then handed over to the scanner for transverse through the frame.

The trim saw is located after the scanner – at a distance of only around 6m (6 lug lengths). From there the boards are sorted into bins before stacking and packing. Figure 30 highlights the scanner and trimmer space.

*Fig. 30: D*TEC BioScan scanner (obscured by walkway) & trimmer (Stimson Lumber Company)*

QUALITY CONTROL

Stimson Lumber employ a leading grader to oversee the operation of the D*TEC BioScan. Their role includes monitoring of the real-time indicators in the software – including trim loss and dimensional summaries – to provide confidence in the scanning solution. The leading grader also coordinates continuous improvement of grading rules, using the board saving functionality to review and facilitate ‘what if’ scenarios.

In this application, the visual grader is located upstream of the scanner – meaning that they cannot visually verify the quality of product after trim decisions have been made. The mill therefore also uses the operator located at the unscrambler/autostacker as a 'last check'. This operator is skilled in grading rules and can quickly stop the line should inferior product be noticed.

Stimson Lumber's stud products are produced in accordance with WWPA (Western Wood Products Association) quality requirements. This necessitates strict documentation of production statistics including:

- Weekly audit of production output
- Non conformance reporting including assessment of characteristic types causing the grade decision. In these cases the leading grader investigates the specific boards and may recommend changes to grade rules to avoid re-occurrence.

The mill also maintains machine control checks:

- Weekly calibration (profiling and lamp levels)
- Weekly 'repeatability' checks – involves the re-run of 5-6 boards with 'interesting' characteristics. The boards are re-run in a number of different orientations allowing comparison of scanner decision. Stimson Lumber personnel confirm that the results of these checks show highly repeatable performance.

PERCEIVED BENEFITS

Stimson Lumber assessed the system's performance after 3 months operation. Benefits included a 3% increase in volume output, a 12% increase in value realisation and a significant 50% reduction in trim loss.

The mill has reduced grader requirements from 3/shift down to 1/shift and is currently achieving 5% overgrade and 5% undergrade in finished pack checks. They aim to achieve a tolerance of 1% overgrade and 3.5% undergrade. Refer to Figure 31 for an example of ‘typical’ finished product.

The mill also confirmed that the machine delivers very accurate trim decisions in terms of knot sizing, bow, spring and twist.

*Fig. 31: Hemlock stud material graded by the D*TEC BioScan (Stimson Lumber Company)*

KEY ISSUES

Stimson Lumber personnel stressed that the most significant operational issue for the scanning is cleanliness. The system includes a air purge system on its bottom sensors, but the mill reinforces this with frequent manual air purging. They have gone to the extent of placing a logsheet in the control room to track the cleaning schedule. Ongoing operation without cleaning away debris heightens the risk of incorrect classification – typically leading to product downgrade and excess trimming.

In terms of characteristic classification, they are currently working with CNM to improve the measurement of 'dark' wane and 'steep' wane. The mill is finding that the steep wane is being confused with other characteristics such as stain or bark pockets, while the dark wane is sometimes causing incorrect board profile measurement.

7.3. FinScan – Boardmaster NT

7.3.1. History

A 'full visit' to the Finscan manufacturing facility could not be achieved during the research trip. Instead, general information on this system was gathered during a presentation by ScanWare (who are the North American representative for FinScan) during the Seattle Wood Industry Forum, as well as a site visit to the Durgin & Crowell Lumber Company mill in New Hampshire. Supporting information was also sourced from the FinScan website.

FinScan was founded in 1988 and is based in Espoo, Finland. The company specialise in real-time image processing and optimising systems for the sawmill and veneer industries. The company currently employs around 13 people, with their experience in scanning technology dating back to around 1974.

FinScan have representation in a number of worldwide regions, including the North American representative – ScanWare – based in Portland, OR.

The company markets two major products for the sawmill industry – the Boardmaster and Boardmaster NT. The Boardmaster was introduced in 1990 and employs black & white camera technology for optimised sorting of green lumber. In 1999 the company developed their scanning optimiser technology further with the Boardmaster NT which uses colour cameras for fully automatic grading and sorting of green or dry lumber.

Uniquely, FinScan state that their optimisers provide 'graderless' grading. Their first fully automated system was installed in 2001, at the Stora Enso Tolkkinen sawmill (Finland). Scanware state that the first 'graderless' machine was installed in Canada some 2 years ago.

Customer statistics provided on the FinScan website highlight the number of installations (current March 2005):

- 46 Boardmaster systems installed for green sorting
- 70 Boardmaster systems installed for edger optimising
- 79 Boardmaster NT systems installed for both sawmill and planermill optimising

7.3.2. Machine Description

The Boardmaster NT system is designed for transverse applications. The system consists of two scanner frames mounted behind one another in the direction of board flow, with an automated board turner in between (see Figures 32 and 33 for an overview of the scanner frames and board turner).

The standard system accommodates board lengths up to 6m (special 8m version available), with maximum width 350mm and thickness 125mm. The machine footprint is typically 4 to 6m, with each scanner frame approximately 1.7m in length. The variation in footprint can be attributed to the type of board turner employed – this equipment is third-party sourced.

Fig. 32: FinScan Boardmaster NT – Scanner Frame 1
(Durgin & Crowell Lumber mill)

Maximum production speed is stated at 240 lugs/min for stud lines and around 180 lugs/min for random length material.

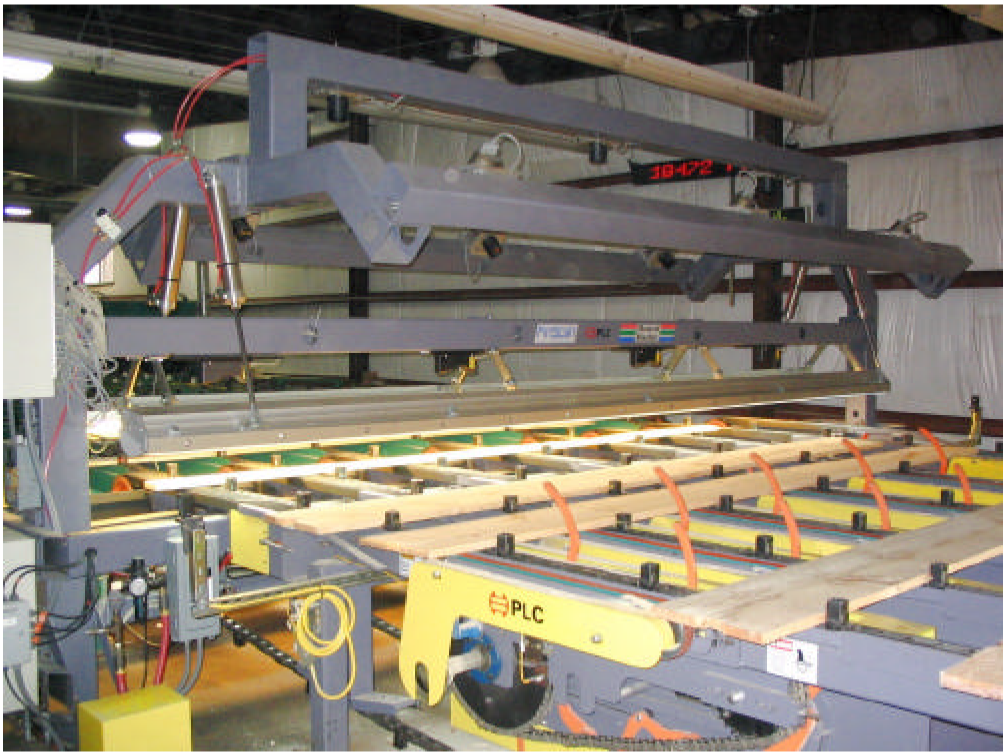


Fig. 33: Scanner Frame 2 & board turner (Durgin & Crowell)

The measurement process consists of the following steps:

- Boards are loaded into lugs upstream of the scanner
- As the board travels under Frame 1, narrow aspect timing belts speed it up to create a 'virtual' lugspace, similar to the CNM D*TEC BioScan – although in this case the lug chains are not terminated altogether.
- As the board passes under Frame 1, 3 cameras mounted in the frame scan the top face. Illumination of the board is achieved using close-mounted fluorescent tubes.
- The boards, still in their individual lug space are flipped by the board turner, exposing the bottom face.
- The boards next travel under Frame 2, but this time scans are taken of the top face, front and rear edges using 3 sets of 3 cameras – with the edge cameras mounted on around a 45 degree angle to vertical.

- Also within Frame 2, a pair of lasers mounted immediately above and below the board measure the thickness. Standard systems use only 1 laser pair.
- The lug chain drive then continues to transport the boards towards a trimmer or binsorter etc (depending on application).

The Boardmaster NT employs between 3 and 5 PCs to manage the image processing and optimising data that can amount to between 10MB and 30MB per board. The more PCs, the greater the production capacity of the system.

The software interface consists of a number of individual modules working off a single database. Each module concentrates on a specific aspect of the system – from grade rule setup, production, to post-production board optimisation analysis. During production, the interface provides concise information on grade solutions, highlighting specific characteristics using colour coding graphics. The user can see the solution for the last 8 boards at one time, and can focus on a specific board to better understand the grade-limiting feature within a given span of the board.

7.3.3. <u>Grading Modulus</u>

The BoardMaster NT provides classification of the following characteristics:

- Knots
- Split
- Rot and red stain
- Blue stain
- Bark and resin pockets
- Wane
- Warp - bow, spring, twist

FinScan acknowledge that there are a number of characteristics that are still very difficult to detect and classify. Compression wood is one of these.

The array of cameras delivers board length image resolution of 0.4064mm and width 0.8382mm – 2.032mm (depending on lug rate). This translates into length measurement accuracy of +/-5.08mm and width measurement accuracy of +/-1.524mm. The laser pair delivers thickness measurement accuracy to +/-1.524mm as well.

Knot sizing accuracy is approximately +/-1mm. The method of knot sizing varies depending on the client's grading standard context. The optimiser attempts to accurately 'match' knots passing through the board to ensure effective sizing. The logic used on a specific board can be viewed in the software such that clients can provide continuous improvement feedback to FinScan on the effectiveness of the match.

Overall, FinScan aim to deliver a system capable of 95% sorting accuracy within a grade. Their performance guarantee is 96% value yield – using accurate product value tables for grade, dimension and length.

7.3.4. Design Considerations

FinScan promote a 'keep it simple' principle in their system design – and aim to deliver solutions that match the visual ability of a human grader. In fact, the company slogan is 'What We See is What You Saw…".

Points of interest in their design include:

- The use colour cameras over black & white. The company has taken this approach to assist in the classification of different knot types.

- The use of relatively standard fluorescent tubes for illumination of the board during scanning. FinScan feel that the availability and long life (12-18 months) of the fluorescent tubes is a design advantage.
- The ability to interface the BoardMaster NT optimiser with mill ERP (enterprise resource planning) systems. This concept aims to effectively integrate realtime production data from the BoardMaster NT with other information systems (eg. inventory, supplier information, order tracking etc)
- The optimiser also accommodates interface with traditional mechanical stress grading machines for cut-in-two solutions based on stress grade.

In terms of future product development, FinScan list the following objectives:

- Tighter tolerances on knot sizing
- Enhanced methods for classifying rot and red stain
- Online species detection
- Sensor development for measuring grain distortion (eg. laser ‘dot data’)
- Enhanced customised software reporting

7.3.5. <u>Quality Control</u>

At the Seattle Wood Industry Forum, ScanWare stressed the point that, although their grading systems are fully automated, there remains a very real need for personnel onsite to be responsible for grading quality. What they promote is that the BoardMaster NT can replace a visual grader’s role, but this process must be backed up with stringent output pack checks etc to maintain quality control.

They reinforce the need for effective shift statistics and alarming functionality in optimising system software. The Boardmaster NT interface provides real-time monitoring of (amongst others) grade recovery, characteristic tally, and ‘reject’ tally.

The software also monitors characteristics on consecutive boards, and initiates an alarm should it see repetition across the faces of the boards – as can happen when the board flipper fails to turn the boards during scanning.

FinScan recommend a number of routine machine control checks similar to most other optical scanning systems – such as regular lens cleaning and light level checks. Interestingly though, FinScan believe that the most critical aspect of machine control is up-to-date product value references. It is the responsibility of the mill to maintain accurate price tables in the software, and FinScan have worked hard to develop user friendly interfaces to help in this regard.

7.3.6. Perceived Benefits

ScanWare promote the following primary benefits of the Boardmaster NT:

- Enhanced product quality
- Less ‘off grade’ product – reduced overgrade and undergrade output
- Reduced trim loss
- Increased production capacity
- Unlimited custom grade setups
- Uniform grade rules across multiple sites – meaning true standardisation of a company’s product
- Quick system commissioning – startup within 1 day of installation

ScanWare also provided an interesting comment regarding the practical implications of their optimisers, and that is the fact that many mill operators are initially ‘shocked’ by the scanner decision – visually the in-grade boards look very different to their typical output. The reason for this is that the optimiser very accurately grades to the limits of the rules, whereas a visual grader tends to be much more conservative. ScanWare sometimes recommend that mills gradually change grade rules to progressively introduce the new ‘look’ to their product.

*7.3.7. **Relevance To Radiata***

FinScan are confident that there scanners work effectively with radiata. There are several black & white BoardMaster systems in operation throughout Australia and New Zealand, whilst the first colour system to be used with southern yellow pine (physically similar to radiata) is due later in 2005.

*7.3.8. **Mill Visit – Durgin & Crowell Lumber Company***

OVERVIEW

Durgin & Crowell Lumber is located in New London, New Hampshire. The mill produces appearance grade products using east white pine resource. Annual production is around 50 million bf. Durgin & Crowell installed a Boardmaster NT in October, 2004.

PRODUCTION SETUP

Unlike the other mill visits discussed in this report, the Boardmaster NT at Durgin & Crowell Lumber is installed in the sawmill – not the planermill. Its role is to deliver trim decisions and sort green boards fresh from the cutting process into specific grades prior to drying. Specific grades are then run through the planermill in a batch process. The optimiser's trim (cut-in-two) decision and grading decision is critical, given that only downgrading to 'reject' can occur in the planermill.

The system is located immediately prior to the sawmill trimmer and binsorter, just downstream of a visual grading station. All product processed is 1 inch thick, while width varies from 3 – 12 inches and length is also variable up to 16 foot maximum (see Figure 34 for an example of 'typical' input material). Maximum production rate is around 80 lugs/min (not limited by the Boardmaster NT).

The visual grader's role is to look for characteristics that they feel the system cannot see accurately. These include:

- Shake
- Rot
- Bark seams

Fig. 34: East white pine resource being processed at Durgin & Crowell Lumber

QUALITY CONTROL

Durgin & Crowell's products are produced in accordance with NeLMA (Northeastern Lumber Manufacturers Association) grading rules and quality control specifications. Implementation of the BoardMaster NT into their grading process was relatively straightforward, although Durgin & Crowell personnel noted that NeLMA's unfamiliarity with scanning systems did present a few issues.

In terms of machine control, the operators conduct a weekly check of light levels on the system. They also conduct 6 monthly camera and laser calibration checks using an aluminium reference bar.

PERCEIVED BENEFITS

Durgin & Crowell personnel believe that the key benefit of the BoardMaster NT is its consistency – it is not sensitive to human nature: "no 4pm decisions". The machine is also considered very accurate and has improved product quality, with an initial analysis highlighting a 3% grade uplift. This is related to the fact that the system always grades on absolute value alone – visual graders tend to make judgements based on 'perceived' appearance characteristics but not necessarily accurate measurement and valuation. As an example, the optimiser may chose a 'short' high grade product trimmed from a 'long' lower grade, whereas the grader would almost always avoid trimming.

The system has also relieved bottlenecking at the grading station, and has been very reliable in operation – with zero downtime recorded since startup (9 hour single shifts).

KEY ISSUES

In terms of machine performance, Durgin & Crowell personnel believe that it only seems to have 'trouble' with certain 'red' knots, where there is little contrast between knot and clearwood. This issue may be similar to a blonde knot in radiata. In these cases, the knot sizing solutions begins to lose accuracy.

Another interesting point is that they still accept that the product value setups are not 100% accurate presently – and this leads to mis-grading. This is not an inaccuracy of the system, but it highlights the issue that it takes significant time to setup product value references, especially relative to complex grading parameters. As with any machine – "nonsense in, nonsense out".

7.4. <u>Innovativ Vision – Woodeye</u>

7.4.1. <u>History</u>

The Swedish company IV Industry started in 1983, specialising in high-speed imaging equipment. Three industrial branches developed within the company:

- DocEye – document scanning technology (eg. speeding tickets etc)
- Image Systems – high speed image processing of diverse events including car crash simulations and missile launches
- WoodEye – wood industry scanning initiatives.

One of WoodEye's first links to the wood industry was from a window manufacturer, who approached the company with a need to scan sections of window frames for characteristic grading.

After a number of restructures and sell-offs within the 3 branches, WoodEye was eventually bought in 1987 by the company Syntrans (80% share), as well as 2 individuals on the board of management for WoodEye. Two 'sister' companies remain, including Shapelite, which specialise in sheet steel imaging.

The first WoodEye system was delivered in 1989 to the Norwegian company SP Windows, for use in a crosscut optimising application. The company soon ventured into automated parquet floor sorting systems and for a time worked with Dimter on complete crosscut optimising solutions. Today the company remains focused on the one WoodEye product line – covering sorting (for structural grading etc), parquet and flooring sorting, and crosscutting.

Located in Linkoping, Sweden, the company employs around 22 people servicing a number of markets – Europe, Japan, Taiwan, Australia/New Zealand, North & South America and Russia. Innovativ Vision believe they have around 60-70% of the worldwide scanning market.

7.4.2. Machine Description

The WoodEye 'Sorter' is the primary system for structural product grading. The 'Sorter' employs similar hardware to the 'Cross Cut' and 'Parquet' systems but uses application-specific software for optimisation. The system is designed for linear applications and accommodates timber of lengths 500mm and over, with widths 30-300mm and thickness 20-100mm. Maximum production speed is specified as 650m/min.

The scanner is relatively compact in design, consisting of a ring approximately 1800mm in diameter. The 4 face scanning sensors are enclosed in the outer ring section, while the boards pass through the centre orifice.

The actual footprint is 1922mm x 1910mm x 768mm (Width x Height x Depth). The outer ring also houses the optimising PC hardware – up to 3 PCs in total – as well as the touchscreen software interface. Refer to Figure 35 for an overview of an installed machine.

Fig. 35: Woodeye Sorter close-coupled to planer (Stora Enso Kopparfors mill)

The measurement process is as follows:

- Boards approach the scanner linearly on a conveyor belt
- An overhead roller (with encoder) at the scanner infeed accurately tracks the board movement as it enters the scan envelope (see Figure 36 for detail of the infeed).
- The board is illuminated in the scan envelope by fluorescent tubes of specific heat and light index.

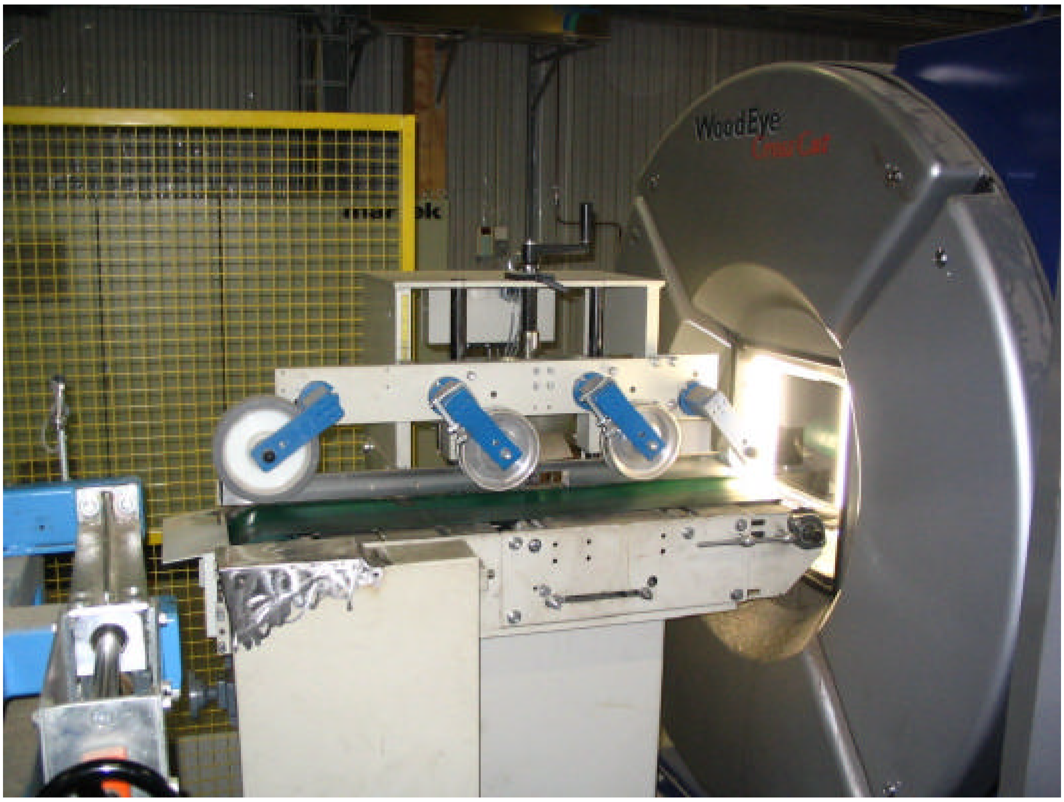


Fig. 36: Woodeye CrossCut – infeed & scanning field (Stora Enso Ala mill)

- Four laser scanners coupled with high-resolution greyscale cameras target each face to measure the board geometry and profile
- These same cameras also house colour multisensors for measuring visual characteristics along each face
- In addition, a tracheid camera sits alongside the first sensors to measure fibre direction
- Another roller on the outfeed to the scanner assists in registration of the characteristics from all sensors. WoodEye have worked hard to ensure data is accurately handed off between encoders as the board travels through – even if there is a speed change in the scanner or if a board stops altogether.

- A third party grade mark printer can be placed on the outfeed to track boards downstream. The inclusion of a grade mark printer can limit production speed.
- Further downstream, clients can opt for an external geometric warp sensor designed to measure bow/spring/twist (see Figure 37).

Fig. 37: Downstream warp sensor (Stora Enso Kopparfors mill)

The software interface is located on the scanner frame itself. During production, the software displays the current board solution and highlights optimal grade decisions for specific board zones. Realtime reporting of grade yield etc is standard, as is a simulation mode to run 'what if' scenarios for grade changes. The software also allows links into production control and planning systems similar to the FinScan. Another interesting opportunity is the 'Yield by Supplier' report that allows the mill to quantify resource value by supplier. This can be a powerful auditing tool for assessing supplier performance.

*7.4.3. **Grading Modulus***

The WoodEye Sorter uses laser triangulation sensors for measuring board geometry and profile. Specific characteristics include:

- Length, width, thickness
- Knot holes
- Wane
- Splits
- Skip
- Mechanical damage

The high resolution black & white and colour camera sensors are employed to accurately measure biological characteristic position, shape and size. Characteristic classification includes:

- Knots
- Resin pockets
- Blue stain – colour camera used for stain distinction
- Presence of pith
- Checks

The laser tracheid sensors provide wood fibre direction data. This is important for effective classification of the following:

- Knots – especially distinguishing dirty surface marks from true knots
- Blue stain
- Rot

WoodEye combine data from the various sensors in an effort to effectively classify characteristics, and mitigate cases of mis-grading. As an example, the system primarily uses the tracheid sensors to detect the presence of knots. It then augments this greyscale camera scan data to identify knot shapes and bark encasement etc. The knots are sized simply by position, width and length. The system does not predict the location of the pith as a means of assisting in knot sizing.

The WoodEye can be interfaced with other grading systems – including x-ray, stress graders and online moisture meters.

7.4.4. Design Considerations

One of the fundamental design principles behind the WoodEye system is the multi-sensor concept – that ‘several eyes are better than one’. The system is modular-based, meaning that customer-specific solutions are possible. Board trials are used to determine which suite of sensors are needed to meet the customer’s grading requirements.

One of the most interesting points in the design of the WoodEye Sorter is the compactness of the system. The frame is constructed of aluminium and plastic, as opposed to the steel section frames typical of the North American style systems.

The system also demands less PC power – with a maximum of 3 PCs required in the frame. The frame itself is climate controlled, and WoodEye personnel are not aware of any temperature effects on the measurement accuracy.

Innovativ Vision use fluorescent tubes for lighting, but initially employed halogen sources. They made this design decision as they feel that halogen light sources generate too much heat and are disadvantaged by their short lifecycle – plus the lighting is less critical to scanning effectiveness due to improvements in camera resolution.

7.4.5. Quality Control

During production the WoodEye uses alarm setups to help alert operators to 'out of control' situations. This strategy is very similar to the other scanning systems. This is coupled with realtime recovery statistics to provide confidence of 'typical' production output.

The WoodEye system is very much designed to deliver 'graderless' grading. Innovativ Vision is currently in the process of gaining European approval for the system to be used in fully automated grading. This will mean fixed, published grade settings for machine control (presumably for specific species).

In terms of sensor calibration and quality control procedures, the WoodEye is no different to other scanners. Daily camera checks are achieved using reference strips to verify sensor colour intensity levels. Realtime outputs from the laser profile, tracheid sensor and greyscale cameras can be checked online using a diagnostics interface.

Interestingly, WoodEye personnel noted that the best system implementations usually saw technically-minded operators from the production line 'championing' the system.

7.4.6. Perceived Benefits

The WoodEye systems are designed to optimise the value yield, and are able to cope with optimisation of a large number of parameters at once. The can also be easily setup to produce customer-specific grades. The systems deliver consistency in grade quality – with reduced overgrading (ie. 'higher risk of customer complaints') and undergrading (ie. 'lost sales opportunities').

Customer justifications for WoodEye optimisers vary depending on the region and intended market. For example, European mills sometimes look to justify the systems based on labour cost reductions (less graders and less risk of worker manual handling injuries). Improved yield and throughput are also critical. In comparison, Baltic State producers are more concerned with improving quality and consistency in their output.

Innovativ Vision feel that they offer a unique value proposition that includes extensive experience (over 20 years) in wood scanning technology. They have familiarity with many different applications – from parquet floor sorting to structural timber sorting to glue laminated feedstock crosscutting. These applications have demanded diverse focus – for example the company has worked for 15 years on perfecting effective parquet sorting based on colour shades. The company has also been exposed to an extensive range of softwood and hardwood species and regions.

7.4.7. Relevance To Radiata

Innovativ Vision are confident that the WoodEye systems work effectively with radiata – given that three WoodEye systems have already been implemented throughout Australia and New Zealand.

7.4.8. Mill Visits – Stora Enso Ala & Kopparfors Sawmills

OVERVIEW

Stora Enso's Ala Sawmill and Kopparfors Sawmill are both located around 300km north of Stockholm, Sweden. They represent two of six Stora Enso mills throughout Sweden, Finland and Estonia that to date have installed WoodEye optimisers.

The Ala mill has an annual production of around 360,000m^3 of sawn pine wood product along with semi-finished components for window frames. A WoodEye CrossCut system was installed around 2 years ago.

The Kopparfors mill has a similar annual production (300,000m^3) but processes spruce resource. The mill installed a WoodEye Sorter on the structural production line less than 2 years ago. The material is visually graded only (no stress grading) and includes product for the Japanese market.

PRODUCTION SETUP

Although the Ala WoodEye is designed for crosscut applications, while the Kopparfors system is a sorter system, they are relatively identical in terms of sensors. Both employ laser profiling, greyscale cameras for visual characteristics and tracheid lasers for fibre direction.

The Ala WoodEye is situated downstream of a moulder, with a short transverse buffer in between. The boards are transported linearly through the WoodEye before being directed on an alternating basis to one of two crosscut saws. Two products are output from the system – fixed length material for longer window frame sections and shorter defect-free finger joint stock. Grade marks are not required, with the WoodEye handing over information to board kickers and the cross cut saws about upcoming board movements and cut solutions.

The Kopparfors WoodEye is installed immediately downstream of a planer (short conveyor section infeed). Boards are scanned before a grade mark printer applies a matrix ID to every fifth board. The product continues through to an external WoodEye warp sensor for measurement of bow/spring/twist. After a slowdown belt the boards change direction and flow transversely, before reaching a visual grading station, lug loader and grade mark reader. The grade mark reader identifies every fifth board that was marked upstream and confirms that board order is being maintained. If not, all boards are downgraded until order resumes. Downstream of the grade mark reader are a set of horizontal bins.

QUALITY CONTROL

During normal production, both WoodEyes essentially operate as fully automated graders. Both mills employ one operator who oversees production along the lines (for example, at Ala one operator looks after the scanner, crosscutters and outfeed).

In the case of the Kopparfors line, the operator oversees production from the grading station. At this location they have a second PC screen to confirm the scanner grading decisions.

In terms of calibration checks, Ala personnel carry out the following activities:

- System clean (especially sensors) once per shift – an air blower inside the frame also controls debris
- Check camera intensity levels once per shift

PERCEIVED BENEFITS

Unfortunately we could not talk directly to mill personnel during the two visits to discuss specific benefits and issues.

8. GROUP (4) – MEASURE EXTERNAL & INTERNAL CHARACTERISTICS

8.1. Coe Newnes/McGehee – Linear High Grader

8.1.1. History

The Linear High Grader is manufactured by Coe Newnes/McGehee – the same company that produces the D*TEC BioScan. Much of the Coe Group's history has been highlighted in the introduction to the D*TEC BioScan. In specific terms though, the Linear High Grader (LHG) originated from the Newnes/McGehee side of the business.

Prior to their acquisition by Coe Manufacturing, Newnes/McGehee had successfully commercialised trimmer, edger and cant curve sawing optimisers during the 1980s and 1990s. During this time the company also developed three machines that would represent the precursors to the LHG:

- XLG – this machine was designed to commercialise the concepts of x-ray density scanning for strength prediction originally developed by Weyerhauser. The machine was designed as a low-maintenance, non-contact MSR grading machine and several installations were completed in southeast US, eastern Canada and the pacific northwest US. Improvements were gradually made including microwave measurement for moisture content and bulk grain angle.
- Transverse Hi-Grade – this machine was designed to optimise geometric characteristics in planed timber. Around 10 installations were completed, and the project highlighted to Newnes/McGehee the difficulties in planermill optimisation
- ADDvantage – this machine is a chopsaw optimiser that incorporates x-ray knot sizing and an early version of the company vision sensor technology. There are around 5 installations currently.

The LHG design draws upon and combines the technology developed for all of these machines, with the commercial product released in 2000. As of January 2005 CNM had successfully installed 21 LHG machines, with half being employed for MSR grading (x-ray and microwave) and the other half for profile scanning and knot sizing duties. The company also has around 5 confirmed sales scheduled for implementation. Of the installed machines, around half are processing SPF (other half southern yellow pine). All are located in the US or Canada.

8.1.2. Machine Description

The LHG is designed for linear timber flow, and can be close-coupled to the planer. The machine has a footprint around 3m long by 3.6m wide, with primary components being the scanner frame and feedframe. Maximum feedrate is around 730m/min (2400feet/min). Refer to Figure 38 for a general overview.

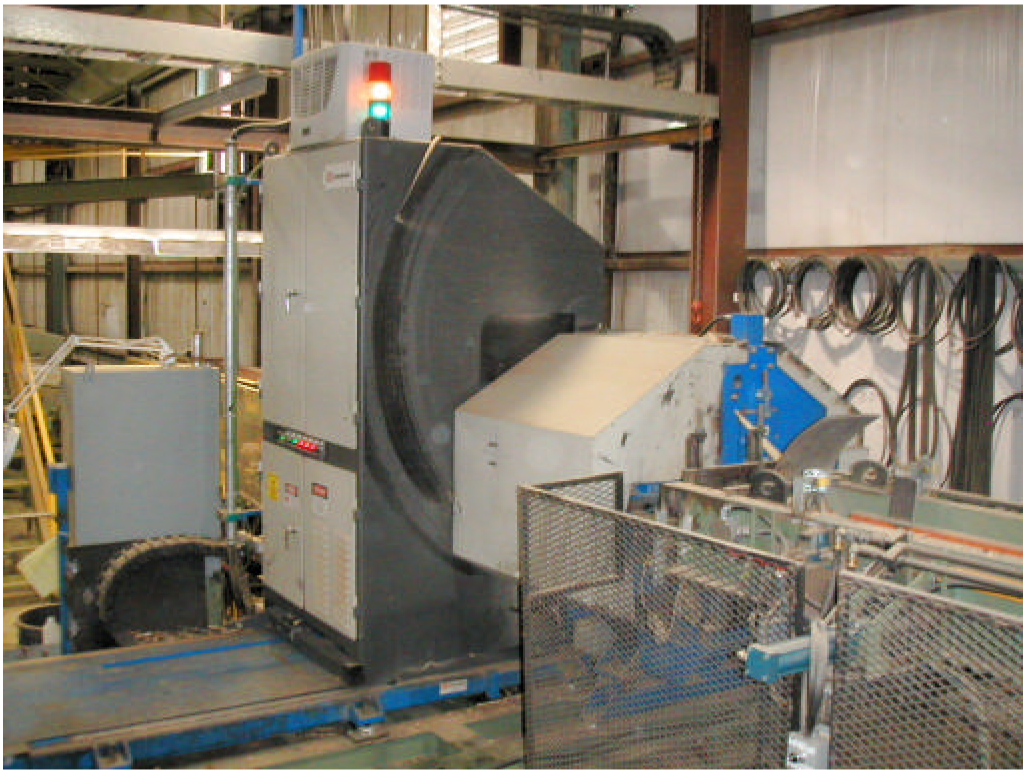


Fig. 38: Linear High Grader (WFM Chasm mill)

Boards approach the machine linearly with infeed controlled by a set of press rollers. The press rollers are part of the feedframe that extends infront and behind the scanner frame. The scanner frame houses the 4 LHG sensors (vision being in beta-test). The measurement process begins when the board breaks a photo-eye beam just downstream of the rollers, also triggering a signal from an encoder on the press roller to allow registration of the different sensor data:

- The first sensor is the microwave sensor. A microwave transmitter is housed above the board, with a receiver horn and receiver below. Two 90 degree out-of-phase microwave signals are focused on a strip along the centreline of the board. Two phases are generated to allow measurement of bulk grain angle.
- Immediately downstream of the microwave is the x-ray sensor. This source also sits above the board, with the x-rays propagating vertically down across the entire width of the board. A detector is housed below to measure the degree of absorption across the section. See Figure 39 for detailed image of microwave and x-ray sensors.
- The third set of sensors is the geometric scanning lasers. A triangulating laser/camera pair targets each board face. Bow cannot be measured by the geometric sensors – but the addition of a simple laser triangulating system downstream of the machine can deliver this information.
- The fourth sensor is the vision sensor, which is currently in beta-test. Basic information on this sensor was provided – that it will direct 1 camera and 2 lasers on each of the four faces. The camera is monochromatic (cyan light source) with different parts of the CCD array designed to measure the various responses of the lasers as well as direct vision feedback. One laser is designed to provide a red light source (different feedback compared to cyan) and tracheid effect, while the other is for 'dot data'. The sensor will be housed within the existing scanner frame environment (I did not get to look closely at this upgrade).

Fig. 39: LHG Microwave receiver with x-ray detector (thin strip) mounted behind (Coe Newnes/McGehee LHG laboratory)

Once the board has passed through the scanner frame it remains under the control of the outfeed press rollers. These ensure consistent speed is maintained during measurement. It is also critical that the board travels centrally through the scanner frame to mitigate any parallax error in the laser scanning.

It is not until downstream that the boards are loaded into lugs. Board tracking is achieved using a 'Domino' grade mark printer at the machine outfeed. This prints a three digit coded ('martian alphabet') number on the trailing end of the board which is read once in the lug space. The system's decision processor keeps 1000 boards in a buffer to allow transfer of grading and trim decision at the time of grade mark reading.

Air cylinders are used to raise the press rollers as well as extend the sensor frame out to accommodate size changes – employing spacer blocks to ensure correct thickness and width for the scan envelope.

The LHG employs a network of 6 PCs to manage the acquisition and processing of sensor data, along with decision making and user interface. All classification logic is software-based (not hardware). Additional PCs may be required to drive the vision sensors. The interface is similar to other systems during production mode – with scanned board solutions depicted on-screen in realtime, and characteristics highlighted to show grade-limiting decisions. The software has extensive menus and screens for product setup and value prioritising. As with some others, it also provides 'what if' re-run scenario capabilities.

8.1.3. Grading Modulus

The microwave and x-ray sensor data is incorporated into 'e-MSR' algorithms for the prediction of board strength (for grading MSR product). Individually, the x-ray sensor maps a two-dimensional profile of material density. The resolution of this measurement is around 2.54mm across the board, allowing the following characteristics to be identified due to their effect on density:

- Knots – knot size calculated using the displacement method
- Resin
- Rot
- Small holes
- Splits
- Checks
- Shake
- Compression wood

The x-ray measurement is sensitive to pockets of variable moisture content. Hence, the microwave sensor ‘normalises’ this to an extent. It works along a central strip on the board with a resolution of approximately 38mm. Two microwave signals are generated out-of-phase, and this phase is measured by the receiver. Because the phase will tend to align with the water molecules in the wood, this coincides with the ‘bulk’ grain angle. This data assists in the e-MSR algorithm.

Overall, CNM are confident that the e-MSR algorithm for sorting MSR product is (at least) as effective as ‘traditional’ mechanical stress graders. This has been reinforced at sites where they have the opportunity to compare recovery from two side-by-side processing lines.

The geometric characteristics are measured via laser triangulation with a resolution of around 7.62mm at 2200f/min (670m/min) feedrate. Width and thickness accuracy is quoted as +/-0.254mm. The system classifies the following characteristics:

- Cross sectional size
- Wane
- Skip
- Large holes
- Spring, twist (twist predicted based on amount of ‘squash’ by press rollers)
- Large splits

The beta-test vision sensor is designed to augment the data from the three existing sensors – CNM refer to this concept of merging data as ‘Data Fusion’.

Specific visual characteristics include:

- Knot type and location
- Local wood discolouration
- Small holes
- Stains
- Small splits
- Machine surface characteristics
- Rot
- Slope of grain (via tracheid effect)

In general, the hierarchy of measurement data in terms of accuracy and quality starts with geometric characteristics. X-ray data is next, followed by microwave and then vision.

The LHG is not currently marketed as a product that can replace visual graders entirely. Although the sensors above aim to classify a significant amount of characteristics, there are some that prove more problematic than others – these are focused on by graders downstream of the scanner (refer to Section 8.1.8 for examples highlighted during the mill visit).

8.1.4. Design Considerations

In many ways the design path taken by the CNM in the development of the LHG is different to other manufacturers. The system began life with geometric scanning, x-ray and microwave, and it is only now that visual camera scanning is being incorporated. This reflects the fact that it 'grew' out of the XLG machine – which was designed specifically as an alternative to mechanical stress grading technology.

In terms of sensor technology, the company feels that the x-ray sensor has been optimised, and they are now at the point of diminishing returns for the sensor design. Efforts are now primarily focused on vision technology and the 'Data Fusion' concept. With the four sensors, the LHG boasts the "highest scan density" in the market.

Coe Newnes/McGehee are acutely aware of possible temperature effects on accurate scanning. As well as providing a robust steel frame for sensor mounting, they have also worked hard to restrict the linear length between first and last sensor (around 460mm) to ensure effective registration of characteristics.

In terms of software interface, the company have strived to deliver a system that facilitates a very detailed level of product setup flexibility, with a significant number of individual parameter rules and customisation opportunities. They have had to develop 'new' grade rule terms that are not part of existing (North American) grading language to aid in this flexibility. The flipside to this design consideration is also the effort that has been put in to ensure that, if mills only want simple grade rules, then they can be quickly and easily implemented too.

It was noted that the 'weak' link in the system is the ID printer used for board tracking. This third-party system is not designed specifically for planermill use, and is known to be sensitive to debris and other environmental factors. CNM are currently working on housing the ID printer in an environmentally sealed enclosure.

As far as future development goes, the company feels that the fourth vision sensor will represent the completion of the hardware design cycle.

Future work will intensify the focus on software development – classification logic and general user interface (GUI) functionality. CNM see themselves as a 'longterm player' in the optimisation field, and aim to maximise the appeal of their systems to a broad range of customers.

8.1.5. Quality Control

As with most of the optimising systems, CNM do not typically place a software interface panel at the visual grading location – it is more likely to be in a control room nearby. Operators rely on system flags and alarming to remain confident of the optimisers decisions. Examples include alarm setups for 'low grade' decisions (where consecutive boards are being all downgraded) and 'undersize' alarms. In terms of board tracking, the ID reader provides information on confidence levels concerning grade mark reading (can uncover poor marking, out-of-order boards, missing boards etc).

Coe Newnes/McGehee rely on their binsorter 'Wintally' control system to facilitate output checks – where the system will automate the selection of certain number of boards from a particular grader. These QC checks invariably confirm the accuracy of both the visual grader and the LHG, whose decisions combine to produce the final solution. Future development will see this enhanced via the LHG software interface.

Maintaining product quality relies on good operator practices in terms of cleaning and attention to sensor status. To aid in this, the LHG incorporates a blower to remove debris from the bottom sensor. The system also uses roller scrappers to minimise resin buildup. Because the encoder uses the circumference of the roller to measure board length and register sensor data together, it is critical that resin does not affect this.

In terms of calibration, CNM recommend the following:

- Laser profile sensors are calibrated initially and do not need re-calibration unless a sensor is replaced
- The microwave sensor does not need calibration after the initial setup
- The x-ray sensor has a requirement by the North American grading agencies to be checked every 4 hours during operation. This is an internal calibration check routine. There is also a more thorough annual calibration requirement.
- Sensor diagnostics can be carried out during operation to verify their response.

8.1.6. Perceived Benefits

Coe Newnes/McGehee promote the following benefits of the LHG:

- Accuracy – comparative testing has shown that even very competent graders are still conservative in their decisions. The grader may be accurate 50-55% of the time while the LHG is accurate over 95% of the time
- Consistency – grade decisions will always be made to the limit of the rules defined in the product setup
- Labour reduction – although the LHG does not deliver 'graderless' operation, it does reduce the labour requirement. This in turn leads to a potentially safer environment, where workers are not exposed to manual labour risks (eg. carpal tunnel syndrome)
- Product uplift – this relates to 'finding' high grade products within the same resource. This addresses the issue of "money left on the table" by providing operators with better recovery of the grades that (typically) have the highest margin
- Reduction in trim loss – due to more precise trimming decisions

- Increased throughput – faster production speeds
- Better control of planermill size – accurate cross sectional measurement at the LHG allows extremely quick feedback for planer setup
- Reduced maintenance costs – compared to mechanical stress graders.

CNM personnel have received feedback from at least one client that believes that "no other piece of equipment in the industry provides the same payback" as the LHG.

In terms of offering a unique value proposition, CNM have aimed to position themselves with superior service and a commitment to expert client training. This is delivered via an engineering staff of over 100 people and a service department numbering over 45.

8.1.7. Relevance To Radiata

The LHG is designed with a range of tune-able parameters that assist in optimising sensor feedback for different species. During production the system must be set to the correct species to ensure decision accuracy. This is a straightforward issue in North American terms – given that species cannot be mixed, and must be 'batched' during production. In the context of MGP, species mixing is allowed as long as the structural properties of the output are maintained. Hence, the need to maintain appropriate species setup would have to be closely controlled somehow.

CNM confirm that radiata pine has been successfully trialled at their laboratory. It should be remembered also that the LHG was first optimised for southern yellow pine – which is physically very similar to radiata.

One characteristic in Australian radiata that is somewhat unique is occluded knots. Because the mills that (to date) have implemented LHG machines have processed natural forest resource rather than plantation timber, the LHG has not had to make decisions about knots in pruned branches. This may not represent an issue at all, but this does highlight the fact that it is not just the species but also forestry practice that is important when customising a system for a particular operator.

8.1.8. Mill Visit – West Fraser Mills (WFM) Chasm

OVERVIEW

The West Fraser Mill in Chasm, British Columbia produces MSR product for the North American market, along with Japanese grade material. The feedstock is 95% western SPF with the balance douglas fir. Overall production is around 300 mbf/year.

The West Fraser Mill company has 14 solid wood mills. Six of the mills employ LHG machines in grading and optimising while another 7 use Autolog LPO systems. The reason for the different equipment is mostly due to the acquisition of another company. The Chasm site represents a test site for the LHG system, which was installed in December 2003.

PRODUCTION SETUP

The MSR line at Chasm processes 2x4 and 2x6 material in lengths 2.4 – 6.0m. The line runs at up to 120 lugs/min, with the speed limited by the planer and not the grading machine.

The LHG system is de-coupled from the planer but remains close to the outfeed.

It contains 4 face geometric laser sensors along with x-ray and microwave for e-MSR algorithms and sorting. There is an inline moisture meter downstream along with three grading stations. The LHG decision is sprayed on each board as it enters a lug space prior to visual grading.

The visual graders focus only on the characteristics that are known to be problematic for the LHG, namely:

- Stain
- Shakes/checks/splits
- Manufacturing defects
- Rot
- Unsound knots

QUALITY CONTROL

The Quality Control system is still evolving – within the mill and in terms of grading agency conformity. The mill uses traditional MSR quality control checks including pack checks and audits of individual graders (using Wintally to segregate). These audits provide the opportunity to verify LHG decision making. QC personnel also carry out and log 4 hourly x-ray calibration checks. Structural properties of product are monitored using traditional CUSUM methods as per NLGA requirements.

Mill personnel acknowledge that the implementation of the LHG has demanded more technically-minded QC personnel to effectively interface and control the system.

<u>Perceived Benefits</u>

WFM Chasm personnel highlight the following benefits of the LHG:

- Very accurate wane measurement and trim decisions – graders tend to conservatively overestimate wane
- Faster production speeds – they believe visual graders would not be able to keep up with a 120 lugs/min rate (even with more than the 3 graders existing)
- Improved grade recovery
- Lower maintenance than a mechanical stress grader

Interestingly, Chasm has actually seen trim increase and not decrease. This is a result of their specific product value setup, and it means that the mill can maintain volume but output higher grade material – which is important considering the export duty that is applied on a per volume basis during export.

KEY ISSUES

Chasm QC personnel highlighted a number of issues with the LHG that they recognise and work with:

- Board tracking is a relatively significant issue – the ID printer/reader system is considered a 'weak' point and limits the overall accuracy of the system
- Microwave sensor is not considered an appropriate moisture meter – the microwave sensor only works across a limited band in the centre of the board. This limitation can be exacerbated when running 2x4 product if it does not track centrally through the machine. In addition the measurement is not considered 'industry standard' and so the mill uses a separate inline meter to confirm MC.

- Grading rules still not perfect – several specific issues remain problematic for the LHG to classify accurately. One example is the difference between a ‘wane dip’ and a ‘corner tearout’. These types of issues require further collaboration with CNM to develop appropriate rules to better differentiate characteristics.
- Initially the mill had a ‘cultural’ issue in training visual graders to only focus on characteristics that the LHG did not classify accurately.
- MSR recovery is probably slightly less than that achievable by a mechanical stress grader.

Despite these points, there is an overall feeling that the company and its personnel very much embrace the technology - even though they acknowledge that it can’t do everything perfectly.

8.2. Lucidyne Technologies – Grade Scan

8.2.1. History

Lucidyne Technologies is located in Corvallis, Oregon. The company is over 20 years old and remains relatively small, with approximately 50 people employed. The company initially represented a technology provider willing to work within a broad range of industries. One of their first big successes came with the development of the Lucidyne grade mark reader. Now a common sight in sawmills, Lucidyne have sold over 600 of the units. This success probably helped the company to form the strategy to focus on the wood products industry.

In 1993 Lucidyne developed a ‘flying saw’ edger that included laser profiling technology. This represented their first scanning/optimising project.

In 1994 the company collaborated with a softwood remanufacturer - Sierra Pacific – on extending the scanning concept to optimise rip saw solutions. The outcome was the RipScan system, which included top and bottom face scanning.

Since this time Lucidyne have continued to work very closely with Sierra Pacific on improving the design of the RipScan – extending scanning to 4 face and developing additional sensor technology to improve the classification process. Two other variants of the design have also been developed – the ChopScan and GradeScan for optimisation of chop saw feedstock and dimensional lumber respectively.

At present, the majority of the system installs are at Sierra Pacific sawmill and remanufacturing sites. This totals up to 3 RipScans, 9 ChopScans and 1 GradeScan across 3 sites. The company has also installed a GradeScan at another North American mill, and is scheduling the installation of 3 more GradeScans this year.

8.2.2. Machine Description

The GradeScan is designed for dimensional lumber optimisation, and represents the focus of this discussion. The technology and design considerations though are consistent with the RipScan and ChopScan.

The GradeScan is designed for linear product flow. It can be close-coupled to the planer but Lucidyne recommend de-coupling if possible to mitigate debris entering the scanner. The system has a small footprint lengthwise - with the scanner frame only 51cm long, plus infeed and outfeed transports that are approximately 1m in length. The scanner width is 2.4m. Refer to Figure 40 for an overview photo of the machine.

Fig. 40: Lucidyne GradeScan close-coupled to planer
(Seneca, Eugene – courtesy Lucidyne Technologies)

The system is designed to accept timber of cross section 1x3 up to 2x14, with no limit on maximum length (current applications go up to 8.5m). Maximum production speed for the GradeScan is around 500m/min (1800fpm). The measurement process is as follows:

- Boards approach the system linearly and control is handed over to a set of driven feedrollers at the scanner's infeed.
- Lucidyne have put significant effort into the design of a very compact 'scanning field'. This represents a length of only 2cm. Within this zone the system acquires data from 3 of the 4 sensors arrays – vision, profile and tracheid.

- The dielectric ‘Throughboard’ sensor for measuring density is mounted independently, and is located at the transition between infeed transport and scanner frame. It uses a series of radio frequency transmitter and receiver pairs above and below the board to measure the response of the wood to electric fields passing in both directions through the cross section (up and down).
- The colour vision cameras are mounted directly above each face, as are the tracheid lasers and associated cameras
- The geometrical scanning cameras are mounted at an angle above each face.
- A halogen light source is used to illuminate the scanning field.
- Warp measurements can be measured by the GradeScan linearly; however the feed rollers tend to straighten out the bow and twist. Lucidyne overcome this in the same way as other systems – with a separate profile sensor downstream of the scanner that measures the unrestrained boards.

The GradeScan has the same need for reliable board tracking (between outfeed and trimmer/sorter lugs) as all of the other linear systems. The company has developed a ‘proprietary non-contact’ technology that is designed to identify and track characteristics unique to every board without any marking. The company was not willing to divulge further information on this at the time of discussions.

The GradeScan is not promoted as a totally ‘graderless’ solution, and Lucidyne recommend that at least one visual grader remains downstream to focus on the characteristics that are different for the scanner to classify. These include:

- Decay
- Timber break
- White speck

The data from the 4 sensors can represent up to 80MB per board. To process all of this information within a practical timeframe, Lucidyne now rely on software-based image processing and classification (as opposed to specialised processing hardware). Their control and optimisation system architecture includes a 'master' and 'acquisition' PC that distributes sensor data to 'Image Processing' PCs. The number of 'Image Processing' PCs varies depending on the application – one current configuration uses 16 of these PCs, while another uses 30. A further 2 'Optimising' PCs are also required. A production panel is mounted within the sensor frame to allow operators quick access to production information – including realtime board solutions.

Internet connectivity is included in the GradeScan system, and Lucidyne highly recommend high-speed internet access to allow remote diagnosis, upgrades and assistance with calibration checks.

8.2.3. Grading Modulus

Lucidyne believe in a multiple sensor philosophy to deliver a 'complete picture'. The human eye is still considered better than a colour camera at interpreting the optical spectrum, and therefore you cannot rely on a vision system alone. For example, the red colour spectrum in the vision system is useful in identifying knots because of its contrast between knot material and clearwood. The tracheid further defines the knot boundaries by providing information on grain deformation. The density 'throughboard' sensor also helps define the boundary as well as provide information on the direction of the knot and therefore knot type.

Another example of the multiple sensor philosophy is comparing sensor responses to help differentiate characteristics. One case is resin pockets. Using vision alone, these characteristics can look the same as a knot.

A tracheid image though looks completely different - resin tends to reflect the laser, producing a lighter patch on the image while knot material tends to absorb the laser light.

Geometric and vision data has a measurement resolution of 1.78mm along the board (at 460m/min throughput). At some faster speeds, this resolution can shift to 3.56mm to maintain resolution across the width of the board. The accuracy of the geometric profile sensors is +/- 0.25mm for width and +/- 0.20mm for thickness.

The colour camera sensors are designed to provide detailed contrast information across the surface of each face, along with specific colour characteristics. In terms of knot measurement, the sensors are designed with an accuracy of +/- 0.41mm, which equates to a knot displacement accuracy of +/- 3.18mm.

The tracheid sensors deliver classification data on:

- Slope of grain
- Stain (where the wood fibres have been eaten away)
- Resin pockets
- Blonde knots
- Surface texture
- Bark on waney surfaces

Combined information from the geometric, colour cameras and tracheid sensors also classify manufacturing characteristics:

- Planer tearout
- De-barker tears
- Saw mismatch caused by dual arbour gang saws
- Skip

The dielectric sensor builds a black & white image which represents the changes in relative densities along the length of the board. It is not designed to determine absolute density. Similar in basic purpose to the x-ray sensor, the ‘throughboard’ sensor relies on certain characteristics having a different density to clearwood. Data from the dielectric sensor (combined with other sensors) assists in classifying:

- Knots
- Stain
- Decay
- Pith location
- Bark pockets

Unlike the Coe Newnes/McGehee LHG, Lucidyne do not aim to use ‘internal characteristics’ (density) to predict structural properties (eg. for MSR sorting).

The GradeScan is capable of delivering 93% grade decision accuracy. This figure can be further improved to over 95% with visual grader input.

The GradeScan can be customised to interface with other grading machines – including Metriguard CLT stress graders and Coe Newnes/McGehee XLG machines, as well as inline moisture meters. In fact, all three scheduled implementations will demand interface with at least one of the above.

8.2.4. <u>Design Considerations</u>

One of the biggest design considerations taken by Lucidyne in the development of their 3 scanners was to move away from specialised hardware-based image processing into full software-based – hence the need for significant numbers of ‘Image Processing’ PCs in the system architecture. They believe that the hardware-based approach is too expense and not as flexible as the latter in terms of updating classification logic or even adding another sensor input.

In addition, this approach allows redundancy, supports many different production speed requirements and uses off-the-shelf PC hardware.

Another significant design factor was the focus on minimising the scanning field. The company had originally planned a modular approach to their sensors – similar to some other machines discussed – but believe it is critical to have a small scanning field to accurately register the data from the four sensors together.

Lucidyne design all their sensors in-house. This ensures exact specifications are met and camera resolution is maximised. They also recognise that lighting is critical. The halogen light used to illuminate the timber produces a wide spectrum of colours that vary in intensity. The vision sensor response to this variation can change depending on light interactions with wood colour as well as location within the scanning field. To ensure ongoing camera sensor accuracy, they use a sophisticated calibration tool (called a 'rabbit') that checks light response at different points in the scanning field.

Another interesting design consideration was the need to install cooling systems within the scanner frame. During the development trials of the ChopScan system, Lucidyne uncovered temperature effects (via normal daytime/night-time temperature cycling) that were causing very slight scanner frame flexure and misalignment of the geometric lasers. Maintaining a constant temperature environment within the scanning frame has mitigated this problem.

Lucidyne are currently working on a new 'sensor #5' that will provide high resolution 'absolute' grain angle and dive angle measurement. The sensor is designed to augment existing data, especially in applications where heavy blue stain tends to mask fibre information from the tracheid and colour sensors.

8.2.5. Quality Control

Lucidyne's software interface includes a very informative production screen that shows the current board solution – detailing geometric profile, colour camera image, tracheid image and 'throughboard' image side-by-side on the one screen. There is a panel incorporated into the machine's sensor frame that allows quick verification of grade limiting characteristics by a visual grader.

As well as this visual 'realtime' confirmation, Lucidyne expect that traditional QC pack checks are undertaken at their customer sites. They also provide a means of generating a 'biased' QC pack – where the system will sort from normal production those boards that are considered as having 'problem' characteristics. Assessment of these boards may help to better understand the accuracy of the grading rule being applied, allowing continuous improvement opportunities.

In terms of calibration, Ludidyne recommend a routine (approximately monthly) check of light intensity levels within the scan field. The 'rabbit' bolt-on calibration tool is used here.

8.2.6. Perceived Benefits

Lucidyne see the following as primary benefits of their RipScan, ChopScan and GradeScan systems:

- Increased value recovery - with better optimisation based on maximising value, the RipScans installed on the Sierra Pacific remanufacturing lines produced increases of around $200,000/month. This was derived from grade uplift equal to around 5%.
- Labour savings – this is especially prevalent with the ChopScan. In the case of the Sierra Pacific remanufacturing line, one ChopScan allows the redeployment of around 5 visual graders per shift. With 6 chopsaw lines and 2 shifts per day this can represent a significant saving.
- Reduced product waste

Lucidyne believe that their value proposition to customers centres on their extensive knowledge of characteristic identification and effective classification. The company's close partnering with Sierra Pacific has allowed this knowledge to develop at a significant pace. Lucidyne also believe that the customer benefits from the 'hard yards' they have had to work through in terms of board control, sensor registration and sensor calibration – all adding up to a very effective softwood grading machine.

8.2.7. <u>Relevance To Radiata</u>

The Lucidyne GradeScan adapts to new species with inhouse board trials to develop specific thresholds for sensor response to the various characteristics. As with the Coe Newnes/McGehee LHG system, different species will have a different 'lookup' table, so production of more than one species at once requires careful control.

Although the scanners have so far only been implemented in North American sawmills and remanufacturing sites, at least one site imports and processes various species from all over the world – include New Zealand and Chilean radiata.

8.2.8. <u>Mill Visit – Sierra Pacific Red Bluff</u>

OVERVIEW

The Sierra Pacific Red Bluff remanufacturing plant is located in Red Bluff, California. The plant takes shop grade lumber from a number of suppliers and produces material for doors and windows. The plant processes around 450,000 bf/day. The process includes ripsawing, crosscutting, finger-jointing and moulding to get construction-ready components.

Feedstock includes ponderosa pine, sticker pine, white fir, douglas fir and radiata (NZ and Chile). The boards are of various widths up to 460mm wide, and the different species are run in batches.

The Red Bluff site has been extremely important in terms of Lucidyne product development. The first 2-face RipScan was implemented here in 1994, and later reintroduced in 2002 with 4-face scanning. Red Bluff also accommodated the ChopScan system trial beginning in 2001, with the production version implemented on their line in 2003.

PRODUCTION SETUP

The production process starts with 2 RipScan lines, with each scanner feeding 1 ripsaw. Labour requirements for these lines have not changed with the implementation of the scanners – although now the operator only has to look after material flow and not make rip decisions.

After ripping, boards arrive at 1 of 6 chopsaw lines. One ChopScan is used to feed 2 chopsaws, and runs at around 146m/min (480fpm). The ChopScans are paired up and an operator is located between the 2 scanners to oversee material flow and visually confirm grading decisions (see Figure 41). Further downstream another operator is located between the 4 associated chopsaws. Labour requirements have reduced significantly with the introduction of each scanner generally replacing 5 visual graders.

The ChopScans are grading for clearwood finger-joint feedstock along with full-length moulding, door and window parts. The characteristic list that has been setup in the software is extensive to ensure effective crosscutting, and includes:

- Wane

- Undersize
- Surface damage
- Brown and blue stain
- Skip
- Pith
- Resin pockets
- Knot heads – defined as small, round, spike
- Kiln stain
- Dark and blonde birdseye
- Cracks (‘small’ or ‘large’)
- Bark pockets

Fig. 41: ChopScans grading for finger-joint feedstock

(Sierra Pacific, Red Bluff – courtesy Lucidyne Technologies)

QUALITY CONTROL

To ensure grade quality is being maintained, the RipScan and ChopScan operators regularly check the production panel on the scanners to confirm grading decisions. They back this up with feedback from downstream machine centres.

The system also has custom alarm setups – one being proportion (%) of board to be chopped out for waste. A maximum limit is set on this, and if breached the saw will not cut the board and the board data will be saved. This allows the operator to check the grading decision and rerun the board if required.

The software also allows Sierra Pacific to measure the quality of material from their various suppliers, by comparing the relative recoveries of claimed grades.

In terms of continuous improvement, the site also undertakes 'biased' sorting of 'problem' characteristics for forwarding to Lucidyne who can then assess the effectiveness of their classification logic.

Calibration checks are carried out every couple of months using the 'rabbit' tool.

PERCEIVED BENEFITS

Sierra Pacific value the consistency and accuracy of the RipScan and GradeScan optimisers. These benefits combine to produce better quality material, increased fibre recovery (around 5% per machine) and increased value recovery.

In addition they have benefited significantly from the opportunity to redeploy visual graders from what was a very labour-intensive chopsaw line. This amounts to around 45 people per day.

KEY ISSUES

Two issues were noted during the Sierra Pacific visit – although one is probably more representative of an opportunity than an issue. The first relates to the cultural change that was necessary during the implementation of the scanners. The company found that they had to invest time in getting the operators on the line to 'trust' the scanners. This meant lots of side-by-side comparisons of rip and chop decisions.

The second issue relates to continuous improvement of grading decisions. Sierra Pacific acknowledge that the scanners are not perfect, and there is still a ways to go in terms of effectively identifying and classifying all characteristics. One example of their continuous improvement initiatives is in fingerjoint stock. Current procedures see not only knot material but also surrounding grain distortions cut out, before the fingers are cut in. Preparing the fingers requires not just the 4mm finger but also a bit of extra length. The question Sierra Pacific is asking is - why not leave some of the distorted grain and knot on during crosscutting, knowing that this will make up the extra length cut during finger preparation? It is clear that the accuracies achieved with the scanner make these sorts of continuous improvement opportunities possible.

8.3. LuxScan

8.3.1. History

A ‘full visit’ to the LuxScan manufacturing facility could not be achieved during the research trip. Instead, general information was gathered during discussions with LuxScan personnel manning their company stand at Ligna+ (Tradeshow, Hanover).

LuxScan formed in 1998 and is based in Luxembourg. The company started with 2 people and has grown to now have around 35 people aboard. The major shareholder in LuxScan is Baumer Holding Group (Baumer Vision Pool), who is a manufacturer of camera technology and image processing equipment.

The company’s first scanning system was the LaserScan, which included 4-face vision for external characteristics. The sensors used on the scanner were designed specifically for wood and LuxScan maintain the licence for these sensors. In 2002 the company introduced x-ray scanning to their suite of sensor capabilities.

The company has 68 installations to date, currently averaging around 20 per year. The company’s traditional market is Europe, but this is now expanding into the US, China and South Africa. Around 90% of current installs are crosscut applications – with LuxScan having an agreement with the Weinig company for providing integral crosscutting/optimiser solutions (in US only).

8.3.2. Machine Description

LuxScan market a range of machines – these include the LaserScan, CombiScan and Xscan-Combi. All machines are designed for linear board flow and can be direct coupled to a planer or moulder.

Physically these machines are not dissimilar to other linear-flow designs with infeed and outfeed controlled by press rollers and encoders to register board data. Production speeds of around 500m/min are capable, depending on the system. See Figure 42 for an overview photo of a LuxScan machine.

Fig. 42: LuxScan system on display at Ligna+

The LuxScan systems are designed with a suite of sensors to meet customer scanning requirements (which can depend on species, key characteristics, resolution demands etc). Sensors include:

- Cameras – black & white or colour scanning cameras for external characteristic classification. Illumination is achieved using LED lights, which are seen to provide better light 'management' and longer life compared to halogen.

- ‘Shapescan’ triangulation lasers – geometric profiling
- Tracheid effect – top/bottom sensors for grain deviation measurement
- X-ray – density profiling for internal characteristics

LuxScan promote the x-ray scanning especially for hardwood applications, where it is acknowledged that external scanning is a more difficult proposition. Interestingly, hardwood applications represent around 90% of LuxScan’s business in the US market.

*8.3.3. **Perceived Benefits***

LuxScan personnel feel their optimisers deliver the following benefits:

- Labour saving – significant reduction in grading labour demands
- Product consistency
- Production speed increases
- Increased yield and reduced waste – ie. provides the opportunity to achieve the same grade outturn from lower quality supply.

*8.3.4. **Relevance To Radiata***

The first LuxScan system was actually installed in New Zealand, and LuxScan personnel believe this was for a mill processing radiata.

8.4. Microtec – Goldeneye

8.4.1. History

The Goldeneye grading system is manufactured by Microtec – who also produce the ViScan. As discussed in Section 6.2.1, a 'full visit' to Microtec was not possible. The following information is based on discussions with Microtec personnel and a website search.

In 2002 Microtec acquired the lumber grading business unit of the company Grecon, including the x-ray products 'EuroGreComat 702/704/706'. They have gone on to further develop the designs that are now known as Goldeneye. Around 80 x-ray machines have been installed world-wide.

8.4.2. Machine Description

The Goldeneye is designed for linear board flow and is produced in two models – the Model 702 and Model 706. Both provide 'multi-sensorial' scanning that includes:

- Laser scanning for geometric measurement
- 4-face colour camera scanning for external characteristics
- Laser tracheid effect
- X-ray scanning for density measurement, knot identification and strength prediction

The Model 706 augments this data with acoustic velocity, which is measured by a ViScan system installed immediately downstream of the Goldeneye machine (once boards have been loaded into lugs). The density and acoustic velocity data combine to provide accurate calculation of dynamic MoE. Both machines accommodate boards up to 500mm wide and up to 150mm thick, with maximum feedspeed rated at 450m/min. Machine footprint is 825x2390mm. See Figure 43 for a depiction of a Goldeneye machine.

Fig. 43: Microtec Goldeneye (courtesy Microtec website)

8.4.3. Grading Modulus

The Model 706 Goldeneye uses x-ray scanning to define a density profile along a board, then a laser interferometer to measure acoustic velocity. This data is combined to deliver a predicted strength profile and stiffness for the board. The x-ray scanning resolution is around 0.8mm across the board and 5mm along the board at 450m/min feedrate.

The repeatability in the x-ray measurement is high – with a coefficient of variation of less than 1% on multiple measurements for the same sample (Giudiceandrea, 2005).

The optical system produces 1200 scans per second for a resolution of 1mm along the board.

Microtec claim that this multi-sensing measurement maximises recovery of stress graded material. Giudiceandrea (2005) notes a coefficient of determination (r^2) of greater than 0.8 for the measurement of strength when discussing the system, and an r^2 of greater than 0.9 for the measurement of MoE.

The company has met the certification requirements for a number of international grading standards, including AS/NZS 1748. Others include DIN 4074 and EN 338.

8.4.4. Perceived Benefits

Microtec believe that the non-contact method of predicting strength and stiffness is a benefit for the Goldeneye system. They also feel that the 'multi-sensorial' approach to these predictions is superior to other methods – and this has direct impacts on structural lumber yield and therefore better utilisation of the fibre resource.

8.4.5. Relevance To Radiata

In talking with Microtec personnel, it is understood that a 200 board trial was conducted on radiata resource at some point using the Goldeneye. This was successful and did not highlight any specific issues for grading the species. No destructive testing was completed at the time to correlate structural properties. As mentioned in relation to the ViScan, Microtec already has European customers aiming to use these systems for grading MGP product for export to our local market.

9. DISCUSSION

9.1. Potential Benefits For Australian MGP Producers

The present Australian MGP grading regime is a two stage process involving mechanical stress grading underpinned by visual inspection. Both Group 1 and Group 2 machines discussed in detail above are designed to only address the requirements of the first grading stage.

Group 3 machines do not attempt to measure or predict stiffness for the purposes of sorting, instead they focus solely on the second stage of grading. Group 4 machines aim to carry out all of the tasks of Group 3 systems, augmenting this with internal scan data to assist in characteristic detection and classification. Two of these four machines also offer the ability to predict strength properties for the purposes of sorting and grading.

This report has highlighted a broad range of benefits associated with the implementation of the various technologies discussed. The majority of manufacturer-claims were readily reinforced during site visits with producers who are reaping these benefits. The following points summarise the potential benefits available to Australian MGP producers.

GROUP 1 – MEASURE E MECHANICALLY

The Metriguard HCLT represents the proven, traditional approach to mechanical stress grading. Although competitive technology is appearing that employs new predictive techniques to obtain a strength and/or stiffness profile, the advantage that both the HCLT (and TMG-16) have is simply that they physically load the material during the grading process.

While competitors assert the advantages of 'non-contact' measurement, there is a definite logic to at least 'proof' stressing the material during production for the purpose of identifying truly low strength portions of timber.

As an alternative to the Metriguard HCLT, the TMG-16 offers a compact, transverse solution for mechanical E measurement. As a relatively new approach, it would be interesting to see how it performs side-by-side with the linear system to test the claims of enhanced reliability and precision of measurement at high production rates.

GROUP 2 – MEASURE ACOUSTIC VELOCITY

The measurement of acoustic velocity, either as a grading modulus on its own or for the prediction of dynamic stiffness represents a direct alternative to traditional mechanical stress grading. The Dynalyse Dynagrade has been readily accepted in certain parts of the European market, and represents a very simple, easy-to-use solution for stress grading. The ViScan is relatively new but exhibits the same potential benefits. Both machines are superior to the Group 1 machines in terms of space, ease of use, minimisation of moving parts and startup/size change procedures. As well as that, the measurement process is very repeatable and correlates well to average stiffness.

GROUP 3 – MEASURE EXTERNAL CHARACTERISTICS

The four machines discussed within this group proved to be very impressive in delivering an alternative to visual grading. It is clear that the technology is still developing, with manufacturers continuing to improve on the resolution and accuracy of existing sensors as well as introduce new sensor types.

The critical aspect to any system's success is its ability to accurately classify characteristics – and the logic in this process also remains a focus for manufacturers.

In acknowledging the above points, it is also clear that machines from Group 3 are delivering quantifiable benefits to producers today. There is definite potential for Australian producers to consider these machines as an alternative to visual grading. Common benefits include:

- Measurement accuracy – these scanners are able to measure knots with accuracy in the order of +/-1mm. Can a grader achieve that on say a knot at the far end of a 6m board, as it travels past at 100 lugs/min?
- Consistency – producers can guarantee the consistency in grading decisions using these machines, and could easily standardise consistency across multiple production sites. Issues such as grader experience and grader interpretation no longer have an effect on product quality. Two comments from QC personnel during the research visits highlight this – "the machine never sleeps" and "there are no 4pm decisions"
- Faster production rates
- Better grade recovery and grade uplift
- Less trim loss – just as accuracy of knot measurement is improved significantly, so too is the measurement of characteristics such as wane (accuracy to well under 1mm). There is no way a visual grader can compete with this accuracy, and will mostly deliver trim solutions that are too conservative in comparison.
- Reduction in labour costs and reduction in corporate risk in terms of worker's compensation claims

It is important to note that none of these machines (with the exception of the Finscan Boardmaster NT) promote a completely graderless solution. What they all deliver is accurate grading of the majority of visual characteristics, leaving the visual grader to concentrate on a specific number of characteristics – which typically represent less than 10% of grade decisions.

GROUP 4 – MEASURE EXTERNAL & INTERNAL CHARACTERISTICS

The machines in group 4 share all of the benefits discussed above for group 3. In addition, they offer the advantage of being able to incorporate data from internal scans to assist in the accuracy of pith location, knot size calculation, knot direction and other characteristic classifications such as shakes, stain, decay and bark pockets. The microwave sensor used in the LHG also provides limited information on moisture content and bulk grain angle.

The benefit of these machines is therefore in being able to provide the best opportunity for reliable characteristic classification via the analysis of response to multiple sensors (or 'Data Fusion' as it is referred to by Coe Newnes/McGehee).

Two of these machines – the LHG and Goldeneye deliver a strength and prediction based on x-ray (and in the case of the LHG – microwave) data. The Goldeneye Model 706 couples their x-ray density profile to the output of the ViScan acoustic measurement to enhance their prediction of stiffness.

Coe Newnes/McGehee believe that their 'e-MSR' algorithms are at least as effective as traditional mechanical stress graders in terms of grade recovery.

A correlation of determination (r^2) value to quantify the effectiveness of this algorithm for strength and stiffness prediction was not available.

Microtec claim an r^2 value of greater than 0.8 for strength and greater than 0.9 for stiffness. On the surface these statistics are indeed exciting, and the potential for Australian producers would be to quantify the performance of these predictors on local resource. Particular focus on low strength 'bad actors' would be useful to better understand the impact from not 'proof' stressing as is the case currently.

9.2. Applicability To Radiata

The research trip provided the opportunity to see firsthand the differences in physical appearance between Australian-grown radiata compared with North American and European species. This allowed an appreciation of the different priorities mills have when grading product – with local focus probably more on knot size and type, compared to the North American focus on issues such as wane (with knots relatively smaller).

In terms of stiffness, species type has no impact on the Metriguard HCLT, which measures 'local' stiffness mechanically. The TMG-16 uses a mechanical measurement, but calculates an average stiffness across the entire piece, while the acoustic machines also calculate an overall velocity for the entire piece. The challenge relating to these machines is in their reliability to identify the strength-limiting impact of radiata knots, as it relates to an entire piece average. All manufacturers are confident that a local application would be successful.

Group 3 machines have all been designed to accommodate different species of softwood (and in some cases hardwoods too).

This is achieved through via tuning of the thresholds that define the different characteristics – for example tuning the vision sensor to the differences in colour and contrast between typical radiata knots and clearwood.

This tuning approach is the same for group 4 machines. For internal characteristics, specific tuning is required to 'train' the x-ray or dielectric sensor to the differences in density between clearwood and knot material in our radiata. In terms of strength prediction using density profiles, this may have to be physically tested using local resource – given that the strength-limiting impact of knots and other characteristics will be different for radiata compared to other species.

9.3. Detection Of 'Rogue' Boards

A 'rogue' board can be defined as being a board that has been graded 'structural' (MGP grade), but has a strength that is much less than the design value for the grade – so much so that any safety margin built into the design value is no longer present. The strength property is critical when considering a rogue, as this is the property that has the biggest safety implications in application (ie. risk of boards failing). Stiffness relates more to utility (ie. excessive deflection).

The term 'rogue' board is not a formal description, more an informal acknowledgement of the inherent variability of softwood, and of the potentially dangerous consequences. Softwood producers obviously work very hard in grading to minimise the potential of rogue boards appearing in structural material. The problem is that it is very difficult to detect a rogue board. The characteristics of a rogue are not clearly defined, and can include (but are not limited to):

- 'dangerous' knots – of variable size located towards the tension edge of the board, that will have significant impact on strength under bending or tension

- significant deviation in grain structure around the knot
- 'diving' grain – where the grain actually slopes steeply into the board causing a virtual discontinuity.

To add to confusion, a rogue can have all of the above, or perhaps just one. Its characteristics, especially those relating to grain structure, are also very difficult for a visual grader to identify and measure.

Mechanical stress grading can be relatively sensitive to slope of grain, but the current presence of rogues means that it cannot guarantee these types of characteristics being identified. The key to better identification of rogue boards may be in the technologies that better measure the physical characteristics noted above. One such technology is the tracheid effect. This technology works by providing a measurable response to deviations in grain structure. Not only does it allow better definition for knot boundaries, but could also be employed to classify specific grain deformations. The challenge will lie in 'training' the optimiser to identify characteristics, and make a decision on their severity.

Of the machines discussed, only those in group 4 (and one in group 3) have tracheid effect sensors. The remainder of the group 3 machines do not, and therefore count slope of grain as a 'problematic' characteristic to classify. Acoustic (group 2) machines provide an average grading modulus for the entire piece, and although the manufacturers believe that the velocity measurement is sensitive to strength-limiting characteristics, they did not indicate performance specific to the detection of slope of grain.

9.4. Applicability To Current MGP Grading Standards & Quality Control Programs

MGP material is graded in accordance with AS/NZS 1748, which requires a two-stage grading process involving mechanical stress-grading followed by a visual inspection for strength and utility-limiting characteristics. The standard notes that the "stress-grading machine sorts the timber on the basis of its modulus of elasticity", but also that "particular emphasis has been placed on producing a Standard that facilitates rather than retards development of technology…"

Hence, it is believed that any of the group 1, group 2 and group 4 machines which use a grading modulus that correlates to MoE could represent an immediate and viable alternative to the 'traditional' approach to mechanical stress grading (as represented by the Metriguard HCLT). These machines are:

- VAB Solutions TMG-16
- Dynalyse Dynagrade
- Microtec ViScan
- Coe Newnes/McGehee LHG
- Microtec Goldeneye

It is noted that the Microtec Goldeneye already meets AS/NZS 1748 certification requirements.

Group 3 machines (and therefore group 4 also) offer significant advantages compared to visual graders, when considering the second stage of the grading process. The machines can be setup to grade based on our local strength and utility-limiting characteristics, although they do not offer a completely grader-less solution. At present, the best compromise may be to have at least one grader remain on the line, who concentrates only on the characteristics not effectively handled by the scanner.

In terms of quality control, one initial observation from mills who had installed machines from group 3 and 4, is that they needed to employ more technically-orientated QC personnel. This comes about due to the need to work with the machine software on a reasonably continuous basis to ensure optimised grading is being achieved (ie. manipulating grade rules, confirming grade decisions etc).

A broader observation concerning QC initiatives for all machines is that there is little evidence of standardised machine control checks. Local producers using mechanical stress graders are likely to be very familiar with the PTC suite of machine control checks (accuracy, consistency and repeatability) that are intensively carried out shift-by-shift to provide confidence in the grading process. These checks were developed by PTC in conjunction with the CSIRO and NSW State Forests prior to the introduction of MGP in Australia.

In comparison, the machine control checks vary depending on the machine, manufacturer and type of sensors. Of the machines investigated, there were numerous manufacturer-recommended checks involving ‘accuracy’ sticks, along with a number of automated calibration-check/diagnosis routines. The frequency of checks was not intensive, nor intrusive, and personnel at the mill’s visited were confident in the ‘in control’ operation of their machines.

It must also be remembered that the machines investigated are all relatively new. Around half of the systems have been on the market for less than 5 years and few over 10 years. Hence, grading agencies are themselves still learning the intricacies of the machines and the sensor technology.

As the systems become more and more commonplace, perhaps agencies will develop standardised checks for operators.

The significant issue to overcome is that each machine, even within a particular group discussed, has a different approach to grading – eg. linear vs. transverse, black & white vs. colour vision, individual vs. multi-sensor.

In the end mills implementing these grading solutions may simply develop machine control checks that reflect their own corporate risk strategy.

10. REFERENCES

Andrews, M. 2002. Wood quality measurement – son et lumière. NZ Journal of Forestry, November 2002.

Anton, A. and Huddleston, E.B. 1967. The grading of timber into stress grades by mechanical means. Forestry Commission of New South Wales.

Anton, A. 1977. Mechanical stress grading of timber and derivation of basic working stresses. 18th Forest Products Research Conference (Melbourne, 1977).

AS 1720.1: 1997. Timber structures part 1: design methods.

AS/NZS 1748:1997. Timber – Stress-graded – Product requirements for mechanically stress-graded timber.

AS/NZS 4063:1992. Timber – Stress-graded – In-grade strength and stiffness evaluation.

AS/NZS 4490:1997. Timber – Stress-graded – Procedures for monitoring structural properties.

Boström, L., Enjily, V., Gaede, G., Glos, P., Holland, C., Holmqvist, C., Joyet, P. 2000. Control of timber strength grading machines. SP Swedish National Testing and Research Institute (SP Report 2000:11).

Boughton, G.N. 2004. Guidance on Compliance Requirements MGP Timber – 2004. Forest & Wood Products Research & Development Corporation.

Boughton, G.N. and Crews, K.I. 1998. Timber Design Handbook (SAA HB108-1998). Standards Australia.

Bucur, V. 2004. Techniques for high resolution imaging of wood structure. Proceedings – 16th Annual World Conference on NDT 2004.

EN519 Structural timber – Grading – Requirements for machine strength graded timber and grading machines. 1995.

Gaunt, D. and Emms, G. 2004. A-Grader: Acoustic grading of structural lumber. Wood Quality 2004 (Conference – Albury, NSW, Australia)

Giudiceandrea, F. 2005. Stress grading lumber by a combination of vibration stress waves and x-ray scanning. Proceedings of Scan Tech 2005 (International conference, Las Vegas, Nevada USA).

Halabe. U.B., Bidigalu, G.M., GangaRao, H.V.S., Ross, R.J. 1995. Nondestructive evaluation of green wood using stress wave and transverse vibration techniques. Materials Evaluation, Vol.55, No.9,pp 1013-1018. The American society for Nondestructive Testing, Inc.

James, W.L., Yen, Y-H. and King, R.J. 1985. A microwave method for measuring moisture content, density, and grain angle of wood. US Dept. of Agriculture Forest Services, Forest Products Laboratory Research Note FPL-0250.

Johansson, C-J., Boström, L., Bräuner, L., Hoffmeyer, P., Holmqvist, C., Solli, K.H. 1998. Laminations for glue laminated timber – Establishment of strength classes for visual strength grades and machine settings for glulam laminations of Nordic origin. SP Swedish National Testing and Research Institute (SP Report 1998:38).

Jozsa, L.A. and Middleton, G.R. 1994. A discussion of wood quality attributes and their practical implications (Forintek Special Publication No. SP-34). Forintek Canada Corp.

Logan, J.D. Bending stress in the Metriguard Model 7200 HCLT and the CLT (Downloaded from Metriguard website: www.metriguard.com)

Nystrom, J. 2002. Automatic measurement of compression wood and spiral grain for the prediction of distortion in sawn wood products (2002:37). Lulea University of Technology, Sweden.

Schajer, G.S. 1999. Lumber strength grading using x-ray scanning. Forest Products Journal J.51(1) pp.43-50.

Shell, D. Stud Mill Top Dog. Timber Processing magazine (March 2005 pp. 8-15). Hatton-Brown publications.

Manufacturer websites:

Autolog:	www.autolog.com
Coe Newnes/McGehee:	www.coegroup.com
Dynalyse:	www.dynalyse.se
FinScan:	www.finscan.fi
Innovativ Vision:	www.woodeye.se
Lucidyne Technologies:	www.lucidyne.com
LuxScan:	www.luxscan.lu
Metriguard:	www.metriguard.com
Microtec:	www.microtec.org
VAB Solutions:	www.vab-solutions.com

APPENDIX A: MANUFACTURER CONTACT LIST

For further information on specific system capabilities and up-to-date specifications please use the following contacts:

Manufacturer	Contact person	Website
Autolog	Sebastien Larouche sebastien.larouche@autolog.com	www.autolog.com
Coe Newnes/McGehee	Mark Maleta mmaleta@coemfg.com (D*TEC BioScan) Richard Herring richard.herring@coemfg.com (LHG)	www.coegroup.com
Dynalyse	Mikael Perstorper mikael.perstorper@dynalyse.se	www.dynalyse.se
FinScan	Jaakko Riihinen jaakko.riihinen@finscan.fi	www.finscan.fi
Innovativ Vision	Stefan Nilsson stefan.nilsson@ivab.se	www.woodeye.se
Lucidyne Technologies	Bill Briskey billb@lucidyne.com	www.lucidyne.com
LuxScan	Jean-Philippe Hildebrand hildebrand@luxscan.lu	www.luxscan.lu
Metriguard	Dan Uskoski duskoski@metriguard.com	www.metriguard.com
Microtec	Armin VonGrebmer Armin.vongrebmer@microtec.org	www.microtec.org
VAB Solutions	Jean Berube jean.berube@vab-solutions.com	www.vab-solutions.com

APPENDIX B: GOTTSTEIN FELLOWSHIP 2005 – ITINERARY

WEEK 1	
Saturday 2nd April 2005 – Sunday 3rd	• Travel: Perth, Australia to Portland, OR.
Monday 4th	• Travel: Portland to Corvallis, OR. • **Lucidyne Technologies** manufacturer visit. • Travel: Corvallis to Red Bluff, CA.
Tuesday 5th	• **Sierra Pacific Red Bluff** mill visit • Travel: Red Bluff to Portland
Wednesday 6th	• Restday
Thursday 7th	• **Coe Newnes/McGehee** manufacturer visit • **Stimson Lumber Co** mill visit
Friday 8th	• Restday
Saturday 9th	• Travel: Portland to Seattle, WA
Sunday 10th	• Restday

WEEK 2	
Monday 11th – Wednesday 13th	• **Seattle Wood Industry Forum**
Thursday 14th	• Travel: Seattle to Pullman, WA • **Metriguard** manufacturer visit
Friday 15th	• Travel: Pullman to Seattle
Saturday 16th	• Travel: Seattle to Vancouver, BC
Sunday 17th	• Travel: Vancouver to Salmon Arm, BC

WEEK 3	
Monday 18th – Friday 22nd	• **Coe Newnes/McGehee** manufacturer visit • **West Fraser Mills Chasm** mill visit
Saturday 23rd – Sunday 24th	• Restdays

WEEK 4	
Monday 25th	• Travel: Salmon Arm to Montreal, Quebec
Tuesday 26th	• **Autolog** manufacturer visit • **Jean Riopel** mill visit
Wednesday 27th	• **Claude Forget** mill visit • **Bowater** mill visit • Travel: Montreal to New London, NH
Thursday 28th	• **Durgin & Crowell Lumber** mill visit • Travel: New London to Quebec City
Friday 29th	• **CRIQ** manufacturer visit
Saturday 30th	• Travel: Quebec to Montreal • Travel: Montreal to Munich, Germany
Sunday 1st May	• Travel: Munich to Hanover, Germany

WEEK 5	
Monday 2nd – Thursday 5th	• **Ligna+ Hanover**
Friday 6th	• Travel Hanover to Goteborg, Sweden
Saturday 7th – Sunday 8th	• Restdays

WEEK 6	
Monday 9th	• **Dynalyse** manufacturer visit • **Derome** mill visit
Tuesday 10th	• Travel: Goteborg to Linkoping, Sweden • **Innovativ Vision** manufacturer visit
Wednesday 11th	• **Stora Enso Ala** mill visit • **Stora Enso Kopparfors** mill visit
Thursday 12th – Saturday 14th	• Travel: Linkoping to Perth & home.