APPLICATIONS OF X-RAY COMPUTED TOMOGRAPHY IN THE WOOD PRODUCTS INDUSTRY

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Abstract: Forintek Canada Corp. and the University of Northern B.C. have recently opened the new *CT Imaging Centre* in Vancouver, Canada. The facility is designed specifically for forest products research and can provide high-resolution CT and radiographic images of logs and other large objects. The system has a 3.5 MeV x-ray source, a scan envelop 1m in diameter by 5m in length, and special equipment for handling large objects. This paper describes the facility, provides a brief overview of wood product research activities, and describes several other practical industrial and research applications.

Introduction: Canada is one of the world's leading manufacturers of forest products, producing about C$66 billion of products annually. The solid wood sector produces about C$30 billion of lumber and panel products, primarily for residential housing construction and renovation. The United States is the largest export market for these products and purchased C$16 billion of goods, or approximately 86% of total Canadian wood product exports [2][1].

Canadian lumber producers have become an important supplier to global markets because of Canada's abundant high-quality forests and favorable currency exchange rates. Lumber companies have also invested heavily in technology to improve manufacturing efficiencies and reduce costs. This strategy has helped the industry remain competitive in spite of increased raw material costs, growing social and environmental pressures, and trade barriers in the important U.S. market.

Forintek Canada Corp. is Canada's national organization for solid wood products research. The company plays an important role in delivering technology to the Canadian wood products industry and has research facilities in Vancouver, Quebec City and Ottawa, as well as 6 regional offices across the country. Forintek is a private non-profit organization supported by contributions from government, industry, equipment suppliers and contract research services.

Forintek provides value to its members by offering technical support services, and by delivering results from a national research program directed by its members. The company works in the areas of wood building systems, composite wood products, lumber manufacturing, lumber drying and protection, and resource assessment.

Forintek Canada Corp. and the University of Northern B.C. recently opened the new *CT Imaging Centre* in Vancouver, Canada. The facility was designed specifically for forest products research but scanning services are also available to companies and organizations with other applications. Funding for construction was provided by the Canada Foundation for Innovation and the B.C. Knowledge Development Fund.

This paper describes the new *CT Imaging Centre*, briefly discusses applications in forest product research, and provides several other examples of industrial and research applications.

[1] All figures are for 2001.

The CT Imaging Centre: X-ray computed tomograghy (CT) is a well established technique that provides nondestructive cross sectional images showing an object's internal features [1]. The mathematical foundation for the technique was developed by Radon in 1917, but it wasn't until the early 1970s that Hounsfield developed the first medical CT scanner. Since that time, CT scanners have become a common medical diagnostic tool and have found increasing use for military and industrial applications.

The *CT Imaging Centre* has the largest CT scanner in Canada. The scanner has an inspection envelope of 1m in diameter by 5m long and an x-ray unit that is approximately 30 times more powerful than a medical scanner. High x-ray energies and a large inspection envelope mean that large, high-density objects that cannot be accommodated in medical scanners can be readily inspected. Large diameter logs, metal castings, geological samples and fossils are some examples of the types of objects that can be readily scanned.

Construction of the CT Imaging Centre started in late 2001. The facility consists of a concrete scanner building that houses the CT equipment and provides radiation shielding, and adjacent office space that houses the control room and electronic equipment. A photograph of the facility is shown below in Figure 1.

Figure 1. The *CT Imaging Centre* at Forintek Canada Corp.

CT equipment was supplied by Bio-Imaging Research Inc. from Lincolnshire, Illinois, one of the few companies that supply high power industrial scanners. The CT scanner consists of a 3.5MeV pulsed linear accelerator x-ray source, a 512-channel linear detector array, and object positioning equipment. A computer workstation running BIR's ACTIS software controls the system, acquires data and reconstructs the CT images.

A special material handling system is used to transport logs and other large objects into the scanner bay and position them on a turntable. Logs are placed vertically and are held at the top with a clamp. Smaller objects are either placed directly on the turntable surface or are held with special fixtures. Figure 2 shows the interior of the scanner bay with a log placed on the turntable.

During operation, objects are positioned between the x-ray source and detector array. The detector measures x-rays passing through the object and data is collected as the object is rotated. Two-dimensional CT images are then reconstructed on a slice-by-slice basis. These images can be analyzed to identify internal features, measure geometry, and characterize material properties. Multiple images can also be assembled to provide a highly accurate three-dimensional model of an object.

Figure 2. Interior view of the CT scanner bay with a log loaded and ready for scanning.

General performance specifications for the scanner are given in Table 1. Objects up to 900mm in diameter, 5000mm long and 2000kg in weight can be scanned, providing x-ray penetration limits are not exceeded. Spatial resolution as high as 0.25mm can be achieved, but actual resolution limits depend on object properties and on the size and density contrast of the features of interest.

Table 1. General performance specifications of the CT Imaging Centre scanner

X-ray source:	3.5 MeV pulsed linear accelerator
Scan envelope:	1000mm diameter x 5000mm long
Maximum object size:	900mm dia. x 5000mm long x 2000 kg
Maximum x-ray penetration:	Water: 100cm Aluminum: 50cm Steel: 20cm
CT slice thickness:	0.5- 5mm adjustable
Spatial Resolution:	Approximately 0.25mm, depending on field of view and object characteristics.
Scan modes:	2nd and 3rd generation CT Digital Radiography

The time required to produce a set of CT images depends on the size and density of the object, the number of CT slices, and resolution requirements. Industrial scanners use second and third generation CT techniques that are slower than the fourth generation spiral-scan method used in medical CT systems. With the Forintek scanner, third generation “rotate” scans can be done as quickly as 20 seconds per CT slice. Second generation “translate-rotate” scans offer better image quality and higher resolution but take from 3 to10 minutes per slice.

Research applications in the wood products industry: Large CT scanners like the one at the CT Imaging Centre have a number of important practical applications for forest products research.

Forintek's resource assessment scientists are using the CT scanner to better evaluate the quality of Canada's forest resource. Sample trees are harvested from selected forestry sites and the logs are scanned to nondestructively measure wood quality attributes like ring width, wood density, percentage of juvenile wood, and branch morphology. This information is being compiled in a comprehensive database, along with data on site indices, silviculture practices, lumber grade yields and mechanical lumber properties. This comprehensive collection of information will help researchers develop better tree growth models and will help forest industry practitioners improve forest management and better match resource characteristics to end use requirements.

Another application for CT scanning is in lumber manufacturing. Today's state-of-the-art sawmills use laser "true shape" log scanners and computerized optimization systems to measure the outer shape of each log and determine the best sawing solution. This is done on-line and in real time, and the results are used to automatically control log breakdown equipment. These types of systems have achieved some impressive gains over older non-optimized equipment, but still provide less than optimal solutions because they only consider external log geometry, lumber sizes and lumber grade "wane" rules. Internal log defects like rot, splits and knots also affect lumber grade and value but are not considered by these systems because they cannot be detected with current scanning technology.

CT scanners can look inside logs and detect important defects before the log is cut into lumber. This has the potential to maximize lumber grade yields and significantly increase the value of lumber produced from individual logs. Figure 3 shows a CT image from a subalpine-fir log. In the full size image, the internal structure of the log is clearly visible and bark, growth rings, and cracks are all easily identified. Higher density areas in the log are indicated by lighter gray-scale values in the image. Higher density regions include the sapwood located under the bark, and decay and wet pockets located near the log's centre. The feature at the 10 o'clock position is a branch knot. Knots and decay are undesirable defects that lower lumber grade and value.

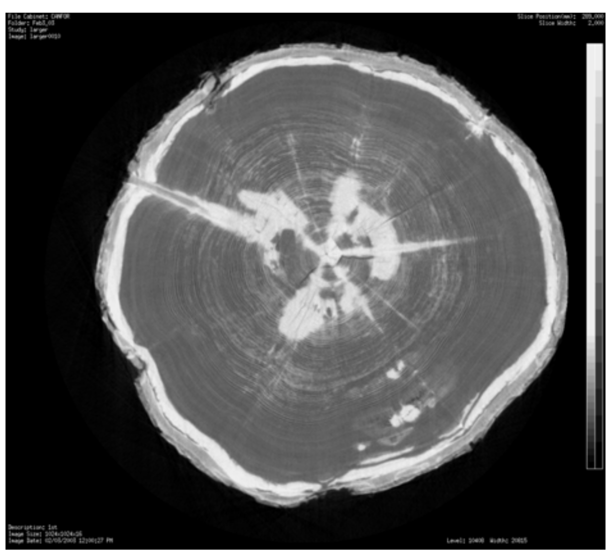

Figure 3. Cross sectional CT image of a subalpine fir log.

Studies done by Forintek scientists and others have estimated that lumber value recovery could be improved by 6-10 percent if internal log defect data were incorporated into on-line breakdown optimization systems [3,4,5]. This level of improvement is worth millions of dollars per year to a typical Canadian sawmill, and would help to maintain profitability despite rising raw material costs.

In spite of the large potential economic benefits, CT log scanners are not yet commercially available. Although a number of equipment suppliers are reportedly investigating the possibility of developing suitable systems, it will likely be a number of years before key technical issues are resolved and fast, reliable and cost effective scanners are available. In the meantime, Forintek scientists are working with equipment suppliers to develop improved scanning systems that identify internal defects based on the analysis of features visible on the log surface. While these systems cannot detect all internal defects, approximately two-thirds of the potential value can be obtained using this approach. Simple x-ray log scanners could also be used to provide supplemental information and further improve the performance of the system. The Forintek CT scanner is an important tool that will be used for research purposes and to provide a benchmark for evaluating the performance of these new systems.

CT scanning is also a useful tool for nondestructively measuring moisture changes in lumber, large beams and poles. This information can be used to study lumber drying processes. Researchers in Sweden, for example, have used CT scanning to study moisture transport mechanisms and found several interesting results challenging traditional drying models [6].

CT scanning can also be used in a number of other forest product research areas. For example, CT scanning can be used to nondestructively measure three-dimensional density profiles in composite beams and wood panels, and can also be used to detect internal voids and other defects. Another use involves scanning lumber, posts and poles to measure the penetration of chemicals following preservative treatments. These and other applications are being investigated by Forintek scientists and will provide unique insight into both the physical behavior of wood and into manufacturing processes. Ultimately, the knowledge gained from this work will provide a benefit to Forintek's members and the Canadian wood products industry.

Other applications:
In addition to serving the forest products research needs Forintek and University of Northern B.C., the *CT Imaging Centre* also provides scanning services to companies and organizations outside the forest industry. CT scanning has many potential applications in research and industry, and has been successfully used in applications as diverse as defect inspection in metal castings, reverse engineering, inspection of sealed hazardous waste containers and examination of fossils. These and other non-medical applications are listed in Table 2.

Table 2. Non-medical applications for CT imaging

Industrial CT Imaging Applications
Inspection of mechanical parts and assemblies: • Nondestructively detect internal defects and anomalies • Accurately measure complex external and internal part geometries • Verify conformance to design specifications • Determine internal structure of composite materials • Verify correct assembly and detect missing parts

• Examine performance under external loads • Investigate failures without disassembly • Reverse engineering – Generate 3-dimensional CAD models from CT data
Examination of sealed containers: • Identify contents of sealed containers and packages • Detect foreign materials or objects • Verify integrity of hazardous material containers
Historical preservation: • Nondestructively examine hidden features • Assess the condition and stability of objects • Pre-conservation assessment
Wood product research and quality assessment: • Scan logs to locate internal defects like knots and rot • Determine moisture distribution, measure ring width and identify the heartwood/sapwood boundary • Inspect lumber and timbers for decay and insect damage • Detect anomalies at glue-line interfaces in engineered wood products • Characterize 3-D density profiles in composite panels
Other research uses: • Measurement of material density profiles • Examination of fossils embedded in rock • Porosity and density measurement of geological samples • Non-contact measurement of fragile structures

The high power level and large scan envelope of the *CT Imaging Centre* scanner mean it's particularly well suited to scanning large metal parts. Recently, a number of steel castings were inspected to investigate a casting problem. Gasses trapped in the mold were causing a small void to form in an area were a threaded fastener hole was required. This was problematic from a manufacturing standpoint because it was leading to failures of the high-speed tooling used to thread the hole. When a failure occurred, the part was ruined and the manufacturer experienced considerable cost and downtime to replace the broken tool. Parts sent to the *CT Imaging Centre* were first inspected using digital radiography to locate areas of interest. These areas were then examined in more detail using CT scanning. Figure 4 shows an example of a digital radiograph and two corresponding CT images taken through the threaded hole and casting defect. The detailed information provided by the CT images helped the manufacturer better understand the extent of the problem and helped them work with the foundry to eliminate the defect.

Another application involved scanning a steel casting for a company that wanted to make several identical copies. The casting had a fairly complicated shape so contact measurement techniques could not be used to measure the internal geometry. By taking a series of CT slice images along the part's length, the cross sectional shape of the part was accurately determined. This information was used by the company to develop a three dimensional CAD model that was later used to create a mold for the castings.

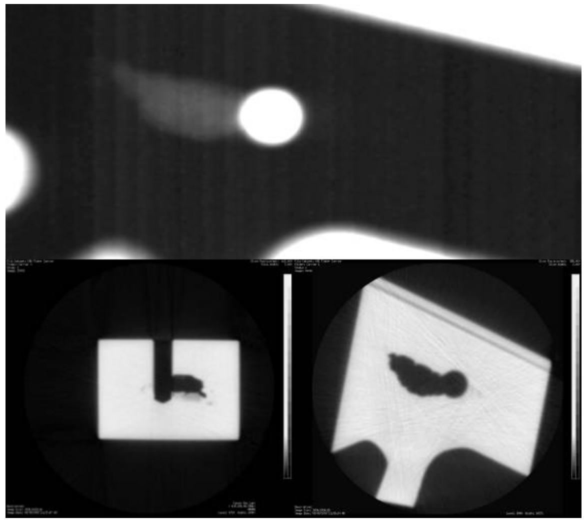

Figure 4. Digital radiograph of a metal casting with a defect adjacent to a threaded hole (top image). CT images taken through the defect are shown below.

The CT Imaging Centre was also involved in a project to nondestructively examine an artifact from a local museum. The item was an unusual bent-wood box made by coastal first nations people, and is shown in Figure 5. The sides of the box were constructed from a single board bent into a complex figure eight shape and attached to a carved base. Museum staff members were interested in determining exactly how the base and sides of the box were joined together. CT scans were taken of the base and lower sides of the box, and an example is shown in the figure. The bright dots within the sides of the box are from a high density cord, possibly made from tree root, that was used to stitch the box together. By assembling a series of CT slices, a three-dimensional picture of the stitching pattern was developed that helped museum staff better understand how the box was made.

Figure 5. A first nation's bent-wood box (right) and corresponding CT image (left).

Conclusions: CT scanning is a powerful technique that can be used to nondestructively examine the internal features of an object. CT images show variations in material density and can be used to characterize material properties, identify defects and measure part geometry. Multiple CT slices can also be assembled to create accurate three-dimensional models that can be used for a variety of different purposes.

The CT Imaging Centre at Forintek Canada Corp. is the largest industrial CT scanner in Canada and was designed specifically to meet the needs of forest industry research. Forintek scientists are using the scanner to nondestructively inspect logs for applications in resource quality assessment and sawmill breakdown optimization. The scanner will also be used to measure density profiles in composite wood products and to measure moisture content and chemical penetration for wood drying and preservative treatment work.

The CT Imaging Centre scanner has also been used by several companies and organizations for nondestructive inspection purposes. The large scan envelope and high x-ray power make the scanner ideally suited for inspecting large parts and high-density objects. The scanner has been used for inspecting large steel casings for defects, for reverse engineering of parts with complex internal features, and for nondestructive examination of museum objects.

References:

1. Anon. ASTM E1441–93: Standard Guide for Computed Tomographic (CT) Imaging. Annual Book of ASTM Standards, American Society of Testing and Materials, West Conshohocken, PA.
2. Industry Canada website: www.strategis.gc.ca.
3. Wagner, F.G.; Taylor, F.W. Simulated sawing with a chipping headrig. Forest Prod. J. 25(10): 24-28 (1975).
4. Steele, P.H.; Harless, T.E.G.; Wagner, F.G.; Kumar, L.; Taylor, F.W. Increased lumber value from optimum orientation of internal defects with respect to sawing pattern in hardwood sawlogs. Forest Prod. J. 44(3): 69-72 (1994).
5. Orbay, L. Using external and internal log characteristics for stem and log breakdown optimization. Report No. W-1826, Forintek Canada Corp, Vancouver, Canada (2001).
6. Wiberg, P. X-ray CT-scanning of wood during drying. Doctoral Thesis, Luleå University of Technology, Luleå, Sweden, 2001.