MOISTURE CONTENT MEASUREMENT IN SCOTS PINE BY MICROWAVE AND X-RAYS

*Tommy Vikberg**
PhD Student
Division of Wood Physics
E-mail: tommy.vikberg@sp.se

Johan Oja
Adjunct Professor
Division of Wood Science and Technology
E-mail: johan.oja@norra.se

Lena Antti
Associate Professor
Division of Wood Physics
Luleå University of Technology
SE-931 87 Skellefteå, Sweden
E-mail: lena.antti@haparanda.se

(Received November 2011)

Abstract. There is demand in the Swedish sawmill industry to improve the accuracy of moisture content measurements, both to obtain a better tool to run production and to ensure that the products meet customer expectations. In this study, 240 well-conditioned pieces of Scots pine (*Pinus sylvestris*), sorted into five different groups by visual inspection, were measured using microwaves and X-rays. Models to predict moisture content of wood were made by measurements of an additional 45 pieces of wood. Using only measured quantities from the microwave system, ie attenuation and phase shift, the root mean square error (RMSE) of the estimated moisture content was 1.00%. By adding total density from the X-ray measurements, RMSE of the estimated moisture content was lowered to 0.89%. Mean errors of the different wood groups varied from –0.65 to 0.18%.

Keywords: Wood, inline, attenuation, phase shift, knots.

INTRODUCTION

Higher production rate and less time from the felling of trees in the forest to the final product, driven by economic and qualitative factors, have led to an increased demand during the last few decades for accurate and automated measuring devices. Because wood shows great variations in properties among individuals and even within the same individual (Dinwoodie 2000), this task has proven to be a challenge. Nevertheless, it is important to obtain as high a value as possible out of the wood to sort the wood to the best designated end product and to ensure that the quality demands of the end product are fulfilled. Moisture content is one quality factor that is important in the production chain and in the final use of the wood (Esping et al 2005). Industrial tests of commercial inline moisture content meters have shown low accuracy from individual readings (Esping 2003; Nilsson 2010). All methods for measuring moisture content have their pros and cons, and most of today's meters only use one measuring technique (Vikberg 2010). Nilsson (2010) demonstrated that accuracy of moisture content measurements can be improved by taking the visual properties of wood into account. Because sawn wood is often sorted according to different qualities by visual methods using parameters such as number of knots, knot size, and wood defects, it would be straightforward to use this information together with the moisture content measurements.

---

* Corresponding author

Wood and Fiber Science, 44(3), 2012, pp. 280-285

Microwaves have been widely used to predict different wood parameters (Schlemm 2004; Schajer and Orhan 2006). A high microwave frequency gives high-resolution measurements, but one needs to be aware of the risk of the phase shift exceeding 2π (Hansson et al 2005). However, if wood density is known, it is likely that a model will be able to predict the number of multiples of 2π that the phase shift has expired. One way to achieve high-resolution density measurements of wood is by computer tomography (CT) (Lindgren 1992).

This study considers moisture content measurements taken with microwaves and combines these measurements with density measurements performed with a medical CT scanner. The tested material was manually sorted into five different groups based on its visual properties, and the potential for increased accuracy in moisture content measurements is discussed according to the results.

MATERIALS AND METHODS

The tested material consisted of 195 pieces of Scots pine (*Pinus sylvestris*) planed on four sides to dimensions of $44 \times 120 \times 920$ mm^3 (R, T, z). The pieces were chosen to represent different kinds of wood, and by visual inspection, they were divided into the following groups: normal, fine, knot, check, and defect. Each group was found in two different moisture content classes conditioned to approximately 13 and 16% MC. Characteristics of the different groups are as follows: the defect group contained large wood defects, such as top rupture and spike knots; the knot group contained considerably large sound knots; the check group contained checks that were easily discovered with the naked eye; the wood classified as fine had very few and small knots and most of the samples had a high amount of heartwood and an average dry density higher than the other groups; finally, the normal wood was chosen to represent the most common wood at a normal production site. From an end user's viewpoint, the fine group would be suitable for window frames, the defect group would be suitable for packaging, and the other three groups would normally be used as construction lumber. Typical magnitudes of some of the characteristic properties of the different groups were measured and are presented in Table 1.

Table 1. Typical magnitudes of some characteristics of wood in the different groups.[a]

Group	CL (mm)	CW (mm)	No. of KW	Max KD (mm)	FD (mm)	$\rho_{0,u}$ (kg/m^2)
Normal	0	0	1.7	23	0	400
Fine	0	0	1.3	7.5	0	450
Knot	0	0	2.2	34	0	400
Check	430	0.5	1.5	11	0	430
Defect	0	0	1.5	21	160	400

[a] Only the central 0.6 m of each board is considered because this was where the actual measurement took place.

CL, check length; CW, check width; KW, knot whirls; KD, knot diameter; FD, fiber disturbance; $\rho_{0,u}$, density of dry wood at MC u.

All pieces were measured with Satimo microwave equipment (Satimo Microwave Vision Sweden, Allingsås, Sweden) using a frequency of 9.375 GHz (Johansson 2001). The measured quantities were attenuation and phase shift in two directions of polarization, corresponding to parallel and cross-grain. The influence of the dielectric properties of the wood on attenuation and phase shift of the microwave was described by Hansson et al (2005), whereas Schajer and Orhan (2005) described a method to measure these quantities. Wood density, $\rho_{u,u}$, where u is moisture content of the pieces, was measured with a medical CT scanner (Siemens Somatom Emotion Duo; Siemens AB, Upplands Väsby, Sweden), as described by Lindgren (1992).

During measurements with the microwave equipment, the short ends of the boards were placed on metal supports, giving rise to some disturbance

Figure 1. Three characteristic boards from the normal group.

Figure 2. Three characteristic boards from the fine group.

Figure 3. Three characteristic boards from the knot group.

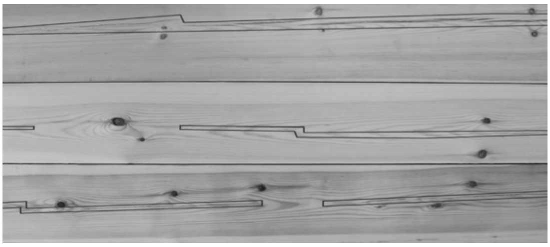

Figure 4. Three characteristic boards from the check group (checks are outlined).

of the measured values within the vicinity of the supports. Therefore, only data from the central 0.6 m of each board were used for further analysis. To give an idea of the visual appearance of board characteristics, three representative boards of each group are shown in Figs 1-5. Only the parts of the boards from which data were collected, ie the central 0.6 m, are shown.

Before the wood pieces were removed from the conditioning chambers, each piece was sealed with glue at the ends to prevent longitudinal drying. Additionally, all boards were wrapped in plastic together with other boards from the same moisture content class to prevent large moisture content changes.

Figure 5. Three characteristic boards from the defect group. (Note large areas of grain deviations.)

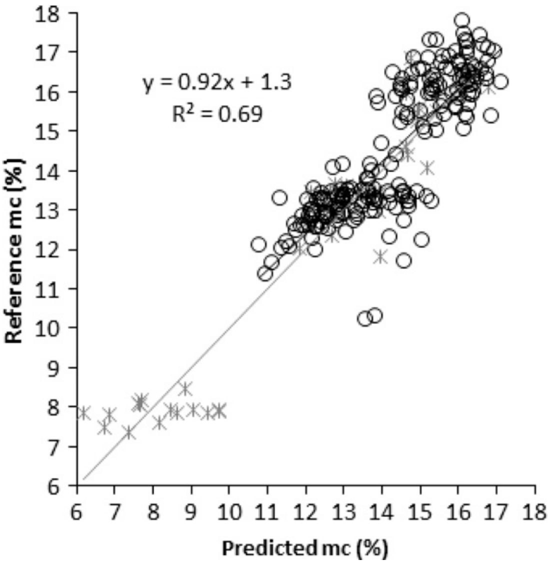

Figure 6. Predicted moisture content (MC) using a model based on measured microwave attenuation and phase shift. Stars represent calibration boards, and circles represent boards for which MC is predicted. The equation in the plot is a linear least square fit to the prediction set.

As a calibration set, 45 pieces conditioned to three different moisture content classes of approximately 8, 13, and 16% were used. Characteristics of the wood used for calibration were the same as for the normal group. The calibration set was kept relatively small to correspond to an industrial calibration procedure. The moisture content, used as the reference, of each individual piece was achieved using the oven-dry method as stated in CEN (2002).

Measured data were analyzed by constructing a partial least square regression model using

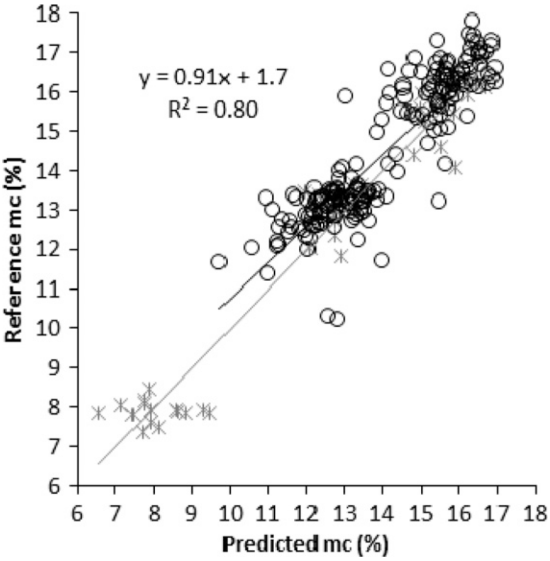

Figure 7. Predicted moisture content (MC) using a model based on measured microwave attenuation and phase shift with density from computer tomography measurements included. Stars represent calibration boards, and circles represent boards for which MC is predicted. The equation in the plot is a linear least square fit to the prediction set.

SIMCA (Eriksson et al 2006). Multivariate data analysis has already shown great potential and has been widely used in wood research (Danvind 2002; Lundgren and Hansson 2007). Two principal components were used in the model to span the space to describe significant relationships in the data. The 45 calibration boards were used for constructing the model, and prediction of moisture content for the remaining 195 pieces was analyzed. In the first model, the measured phase shift and attenuation in the two directions of polarization by means of microwaves was used; the second model also included mean density from CT measurements.

RESULTS

Results from the model predicting moisture content from the measured attenuation and phase shift in the two directions of polarization by means of microwaves are shown in Fig 6.

The calibration set in Fig 6 had a coefficient of determination (Montgomery et al 2004), R^2, of 0.92 and a root mean square error (RMSE) of 0.90%. The prediction set had an RMSE of 1.00% and, as can be seen in Fig 6, an R^2 of 0.68.

To obtain more accurate moisture content measurements, measured wood density, $\rho_{u,u}$, from the CT was used together with the microwave measurements (Fig 7).

Linear regression of the calibration boards in Fig 7 had an R^2 value of 0.94 and an RMSE of 0.77%. The different slopes of the regression lines of the calibration and prediction set show that the calibration was not suitable for all pieces of wood. RMSE of the estimated moisture content was 0.89%.

To gain an idea of possible improvements in moisture content measurements by also using an optical device, mean error and RMSE are presented for the five different groups of wood (Table 2).

As seen in Table 2, RMSE was the smallest for the most valuable wood, ie fine group.

Table 2. Mean error and root mean square error (RMSE) of moisture content measurements for the five different groups of wood.[a]

Group	$\bar{\varepsilon}_{MW}$	$\bar{\varepsilon}_{MW,CT}$	$RMSE_{MW}$	$RMSE_{MW,CT}$	$RMSE^{*}_{MW}$	$RMSE^{*}_{MW,CT}$
Normal	–0.65	–0.55	1.06	0.85	0.84	0.64
Fine	0.18	–0.21	0.64	0.61	0.62	0.58
Knot	–0.36	–0.37	1.06	0.95	1.00	0.87
Check	0.17	–0.33	1.03	0.84	1.02	0.78
Defect	–0.31	–0.59	1.12	1.13	1.08	0.97
All wood	–0.20	–0.41	1.00	0.89	0.92	0.78

[a] Values are shown when only microwave measurements were used and when they were combined with computer tomography (CT) measurements. The two last columns show RMSE after subtracting the mean error for each group, ie the best possible result if combining the measurements with a visual system.

DISCUSSION

RMSE was decreased by adding density measurements determined by CT scanning to the microwave measurements. Adding a third measurement technique would presumably further improve the results. Because the mean errors differ among the wood type groups, a visual system would also improve overall accuracy. If the measurements of a board were taken along the whole length of the board, one could filter out regions in which the signal is stable, which implies that no disturbances such as grain deviation or knots were present. In most cases, however, the boards are cross-fed through the final sorting stations in which the moisture content should be measured. In this case, connecting a visual system to the moisture content meter would be beneficial for detecting objects that are within the meter's measuring range, thus affecting the measured amount.

In the prediction set, there were two points with considerably low reference moisture content. This result was strange because these boards were placed in the same climate chamber as the rest of the pieces in the 13% MC class. There may be some errors in the reference values for those two individuals; excluding them from the prediction set would, however, not produce a remarkable change in the accuracy of the prediction model.

In this study, board thickness was not used as a parameter in the model because the boards were planed to the same dimensions. This step should normally be done because measured microwave values are related to wood and water surface density (kg/m^2), ie the thicker the board, the greater the attenuation and phase shift. A large attenuation caused by high-density wood, high moisture content, or thick boards limits the use of the described system. Generally, the limit is a moisture content of approximately 20% for a 50-mm-thick board with a dry density of 500 kg/m^3. The vicinity of the board's edges will also cause diffraction of the field, and measurements originating from those areas will be difficult to interpret correctly.

An industrial calibration procedure could be simplified if only one board dimension could be used together with preprogrammed correlations for other dimensions. This is concluded because there were problems with the calibration in this study, although only a single dimension with well-defined wood was used. Calibration procedures could also be simplified by using calibration dummies with well-defined dielectric properties.

In summary, this study shows that the accuracy of moisture content prediction was increased by combining microwave measurements with CT measurements. Mean error also differed among the wood type groups, showing the potential to further increase the measurement accuracy by adding a visual system.

REFERENCES

CEN (2002) EN 13183-1. Moisture content of a piece of sawn timber. Part 1: Determination by oven dry method. European Committee for Standardization, Brussels, Belgium.

Danvind J (2002) PLS prediction as a tool for modeling wood properties. Holz Roh Werkst 60(2):130-140.

Dinwoodie JM (2000) Timber: Its nature and behavior. Spon Press, London, UK.

Eriksson L, Johansson E, Kettaneh-Wold N, Trygg J, Wikström C, Wold S (2006) Multi and megavariate data analysis. Umetrics AB, Umeå, Sweden.

Esping B (2003) Test av kommersiella fuktkvotsmätare in-line. Trätek rapport Trätek, Stockholm, Sweden [in Swedish].

Esping B, Salin J-G, Brander P (2005) Fukt i trä för byggindustrin. Trätek, Stockholm, Sweden [in Swedish].

Hansson L, Lundgren N, Antti L, Hagman O (2005) Microwave penetration in wood using imaging sensor. Measurement 38(1):15-20.

Johansson J (2001) Property predictions of wood using microwaves. Licentiate, Luleå University of Technology, Skellefteå, Sweden.

Lindgren O (1992) Medical CT-scanners for non-destructive wood density and moisture content measurements. Doctoral, Luleå University of Technology, Luleå, Sweden.

Lundgren N, Hansson L (2007) PLS models for predicting wood properties from microwave measurements based on three dimensional FEM simulations. Proceedings, Nordic workshop on wood engineering, Luleå University of Technology, Skellefteå, Sweden.

Montgomery DC, Runger GC, Hubele NF (2004) Engineering statistics. John Wiley & Sons, Hoboken, NJ.

Nilsson M (2010) Evaluation of three in-line wood moisture content meters. MS thesis, Luleå University of Technology, Skellefteå, Sweden.

Schajer G, Orhan F (2005) Microwave non-destructive testing of wood and similar orthotropic materials. Sensing and Imaging: An International Journal 6(4): 293-313.

Schajer GS, Orhan FB (2006) Measurement of wood grain angle, moisture content and density using microwaves. Holz Roh Werkst 64(6):483-490.

Schlemm U (2004) Mass and moisture measurement by use of the microwave resonator technique. Technical bulletin, Tews Elektronik, Hamburg, Germany.

Vikberg T (2010) Fuktkvotsmätare för träindustrin: En kartläggning av metoder för mätning av fuktkvoter i intervallet 7-18 fuktkvotsprocent. Technical report, Luleå University of Technology, Skellefteå, Sweden [in Swedish].