INTEGRATION OF THE WAGNER MOISTURE METER
WITH THE X-RAY LUMBER GAUGE STRENGTH GRADER

Gerald A. Ziegler
Weyerhaeuser
Tacoma, WA

Abstract

The X-ray Lumber Gauge (XLG) developed by Weyerhaeuser and licensed to CAE-Newnes Ltd. for commercial production is used in the manufacture of machine-graded dimension lumber products at 20 installations in North America. The XLG measures the density profiles both across and along the board, and predicts the structural properties of each board using algorithms based on extensive testing. With its computer-based operating system, the XLG has the capability to integrate other information into the decision process. This paper describes the integration of the moisture content information from a Wagner model 683 in-line moisture meter with the density information from the XLG to machine grade moisture sensitive products such as glue-laminated beam stock, and high performance floor joists. To obtain accurate moisture content measurements, the Wagner readings are correlated to ovendry moisture content values using a multiple regression approach which includes a correction for density using the measured XLG values. The moisture prediction errors are significantly reduced using this approach compared to the standard calibration process.

Background

The manufacture of machine-graded dimension lumber products sometimes requires that the moisture content be limited to a maximum level due to special application requirements. Examples of these products include laminating stock for glue-laminated beams, and high-performance joist products that have excellent dimensional stability in service. The normal manufacturing process would require that the machine grading system and the moisture measurement system operate as two separate systems. With the X-Ray Lumber Gauge (XLG) manufactured by CAE-Newnes however, the information from the moisture meter can be integrated with the density measurements into the XLG software to make a single grading decision. This simplifies the grader’s decisions since only one machine spray mark need to be considered during the subsequent visual grading process.

Another advantage of integrating the Wagner moisture data into the XLG system is that it can be corrected for density variation as well. Since the density information is collected by the XLG every 0.5" along the length of the piece, the corresponding moisture information gathered by the Wagner model 683 in-line system can be matched with the density information to provide more accurate moisture measurement. The integration process requires a serial interface for the data transfer, and a small amount of software code to calculate the correct moisture content along the full length of the piece.

X-Ray Lumber Gauge

The X-Ray Lumber Gauge is based on a technology developed and patented by
X-Ray Lumber Gauge

The X-Ray Lumber Gauge is based on a technology developed and patented by Weyerhaeuser, and is exclusively licensed to CAE-Newnes for manufacture of commercial systems. The XLG system uses a single X-Ray radiation source and an array of detectors on the other side of the board to measure the density profiles both across and along the length of the material (Figure 1). Each detector measures the X-Ray attenuation for a 1.0-inch wide by 0.5-inch long section of the board as it travels lengthwise through the XLG machine at speeds of up to 2500 fpm. The density profiles provide the average density of each piece, as well as the size and location of knots and associated grain distortion. Since the density of knot wood is nearly twice that of clear wood, the knots are easily identified in the density profiles (Figure 2). Using strength and bending stiffness algorithms, the boards are machine-graded for various applications such as joists, beams, laminating stock, truss components, I-beam flanges, etc.

FIGURE 1. The X-ray Lumber Gauge measures the density profiles both along and across the width of the lumber (2x6 board shown).
Wagner Model 683 In-Line Moisture Meter

The Wagner model 683 in-line moisture meter is widely used throughout the softwood industry for determination of average and maximum moisture content of dimension lumber. The longitudinal or in-line system is installed directly behind the planer, and used to identify material that is outside the acceptable range of moisture content for specific products. Normally the maximum allowable moisture limit is 19% MC for all dimension lumber products manufactured in North America. For specialty products however, other lower limits are sometimes required because of their application. The Wagner 683 system has the capability to set various sprays or indicator levels based on the maximum desired average or peak moisture value along the length of the piece.

Calibration of the Wagner model 683 in-line system is based on selection of a maximum acceptable moisture content level. The model 683 calibration instructions recommend that a "minimum of 50 boards be selected which have an average moisture content approximately equal to your desired target moisture content." This is based on using a calibrated hand meter to determine the average moisture content for each piece. The Variable Sensitivity control is adjusted so that the average error between the model 683 panel meter reading and the hand meter reading for all 50 samples is minimized or near zero. Although this provides a calibration point for the target moisture content for a variety of wood densities, it does not provide for calibration throughout the entire moisture range.
Integrated System

If the moisture data from the Wagner model 683 system is combined with the density information from the XLG system for each board, the effect of density variations on the measured moisture value can be minimized. Additionally, the XLG system provides a software system which can be used to calibrate the measured moisture values from the Wagner model 683 throughout the entire moisture content range. This is done using linear regression techniques.

A linear regression is defined as a correlation between two variables (dependent and independent) which, if plotted against each other, would fit a straight line (Figure 3). In this example, a change in the independent variable "width" results in a prescribed change in the dependent variable "volume" assuming that the other two parameters (depth and height) are fixed. The mathematical description of this relationship is as follows:

\[ Y = B_0 + B_1X \]  
Equation 1

Where \( B_0 \) and \( B_1 \) are coefficients of the regression equation, and \( X \) is the width and \( Y \) the volume. \( B_0 \) is described as the "offset", or the intercept of the regression line on the Y-axis when \( X \) is set equal to zero. In Figure 3 the volume is zero when the width is zero, therefore \( B_0 \) is 0.0. Also, \( B_1 \) is the slope of the regression line or how much \( Y \) changes for a corresponding change in the \( X \) value. In Figure 3 the slope or \( B_1 \) is 1.0 since the volume increases in direct proportion to an increase in width.

![Figure 3. Linear regression example of correlation between width and volume of a hypothetical material.](image)
In the case of the Wagner model 683 calibration process, we have calibrated the meter to accurately read 19% MC using the 50 samples. If we plot the data we see that on average the moisture content on an oven-dry basis is 19% MC when the Wagner model 683 reads 19% MC. If we look at material at different moisture content levels however, and compare the oven-dry moisture content to the Wagner moisture content, we see that the two values may not agree (Figure 4). In this case the slope is not 1.0 because the change in oven-dry moisture content is more than the change in the Wagner moisture value. In addition, the offset is not zero because the regression line passes through a value other than zero when the Wagner moisture content value is zero.

![Graph showing the correlation between moisture content measured by the Wagner model 683 and the oven-dry moisture content. The equation OD = 1.15*Wag - 3.01 is shown.]

**FIGURE 4.** Correlation between the moisture content measured by the Wagner model 683 in-line Moisture Meter and the moisture content determined by the oven-drying method.

The advantage of knowing the regression correlation between these two variables (Wagner moisture content reading and the oven-dry moisture content) is that for any value of Wagner moisture content, we can define the true or oven-dry moisture content value. In Figure 4, the oven-dry or true moisture content is 8 when the Wagner moisture reading is 10. With the integrated system, we can program the regression equation into the XLG software to adjust for slope and offset between these two variables. For any moisture value taken from the Wagner system, we can obtain a corrected or oven-dry moisture value. In addition we can add a third variable to the regression equation (multiple linear regression equation) to obtain a correction for density as well, since we can measure the density corresponding to any moisture reading taken at a same location within the board.
Moisture Meter Calibration Process

In order to calibrate the Wagner model 683 throughout the entire moisture range requires that we collect a large number of samples which cover the full range of moisture content desired, and which have different densities within each moisture level. We selected two-foot long clear material which provided approximately 15 samples in each of 10 moisture classes. The 10 moisture classes began at 6% MC and ended at 25% MC in groups of 2% MC. These 150 samples were selected for all widths of dimension lumber (2x4 through 2x12) at a Weyerhaeuser mill in Arkansas which had both an XLG system and Wagner model 683 in-line moisture system installed downstream of the planer.

The 150 samples were numbered and weighed prior to reading the Wagner model 683 moisture values. The Wagner model 683 sensor was calibrated according to Section 5.4 in the Wagner manual, and the auto zero feature disabled. Before beginning the test, the reset button was depressed and the Variable Sensitivity setting placed at the setting determined using the recommended Wagner calibration process described above for each width of material.

A special jig was developed to hold each sample at the correct height between the electrodes. Care was also taken to ensure that the samples were centered along the centerline of the electrode width by marking an index line on the frame of the bottom electrode with a magic marker. The samples were then placed between the electrodes, and the panel meter reading taken. This process was repeated until all 150 samples for each width were recorded. The data included sample number, the weight when measured, and the Wagner moisture meter reading.

After the 750 samples were measured, they were shipped back to our Technology Center in Federal Way, Washington, to determine the moisture content and density using the oven-dry method. The samples were dried in a walk-in oven at 100°C for 48 hours. A small fan was used to circulate the heated air through the oven. After oven-drying was completed, the doors were opened and the samples allowed to cool for a period of about two hours. At this time, the samples were re-weighed, and the width, thickness and length determined using a vernier caliper. Oven-dry moisture content and density were calculated, and the multiple regression equations developed for each width.

Multiple Regression Approach

The correlation between the Wagner moisture content value and the oven-dry moisture content involved two independent variables, Wagner moisture meter reading and wood density. By completing the regression analysis in two steps, the prediction accuracy improvement could be determined independently for slope and offset, and then for density. First, the samples were ranked according to their density value within each width. From this ranking the central third (or about one-half of the standard deviation of the density measurements) were chosen to determine the slope and offset value between the Wagner moisture meter value and the oven-dry moisture content, independent of density effects. Once the slope and offset were determined, the remaining Wagner values were corrected using this regression equation (Figure 5).
In order to determine the density correction, the errors between the new Wagner values (corrected for slope and offset) and the corresponding oven-dry moisture values were determined. These error values were plotted against the oven-dry density values to provide an adjustment to the corrected Wagner value for density (Figure 6). Both of these linear regressions equations were then programmed into the XLG software so that the corrected moisture content could be determined for each board processed through these two systems.

Results

The results of this system integration are shown in Figures 7 through 10 for 2x6 and 2x10 southern pine lumber. Figures 7 and 9 show the original Wagner moisture content value plotted against the true moisture content determined using the oven-dry method. Figures 8 and 10 show the corrected moisture content taken from the XLG system plotted against the true moisture content determined using the oven-dry method. The improvement in prediction accuracy is very apparent by the reduced scatter of data points about the regression line.
2x6 Density Correction
Based on Corrected Wagner MC Values

\[ y = -26.90x + 14.746 \]
\[ R^2 = 0.654 \]

**FIGURE 6.** The density correction for 2x6 southern pine using the corrected Wagner moisture measurement values.

Original Moisture Correlation
2x6 S. Pine

\[ OD\ MC = 1.49\times\text{Wagner MC} - 2.64 \]
\[ R^2 = 0.73 \]
\[ \text{RMS} = 4.06 \]

**FIGURE 7.** The original calibration of the Wagner model 683 in-line moisture meter for 150 pieces of 2x6 southern pine lumber.
Two parameters, $R^2$ and RMSE, describe how well the data fit a linear regression process. The $R^2$ term describes how well a line fits through the data. The closer the value is to 1.0, the more linear the correlation between the two parameters. The second term, RMSE, describes the error about the regression line. The smaller the RMSE term the less scatter about the regression line, or the smaller the error in the prediction of $Y$ for a given $X$ value. The small prediction error is obvious in Figure 10 where the RMSE decreased to 1.66% MC after applying the slope, offset and density corrections. In other words, the prediction error (one standard deviation) at the mid-range of the data decreased from $+ 3.30\%$ MC to $+ 1.66\%$ MC using the integrated system approach.

An indication of the improvements in the moisture content prediction accuracy for all five widths of southern pine lumber are shown in Figure 11. The average prediction error throughout the moisture range (6% to 25%) using the original Wagner calibration process was $+ 3.75\%$ MC. With the addition of slope and offset, the prediction error was reduced by 30% to a value of $+ 2.60\%$ MC. With the additional density correction using the XLG process, the prediction error was reduced to less than half of the original error to a value of $+ 1.55\%$ MC.
FIGURE 9. The original calibration of the Wagner model 683 in-line moisture meter for 150 pieces of 2x10 southern pine lumber.

FIGURE 10. The same data as in Figure 9 corrected for slope, offset, and density.
FIGURE 11. The improvement in prediction accuracy (lower prediction error) for the Wagner model 683 in-line moisture meter using the XLG system and integrated software approach.

Conclusions

The integration of the CAE-Newnes XLG process with the Wagner model 683 in-line Moisture Measurement system provides a significant improvement in moisture measurement accuracy throughout the normal range of moisture content measurement. Although both pieces of equipment are available at only 20 facilities within North America, the process demonstrates the potential improvement in moisture measurement accuracy using this approach.

For those mills that do not have an XLG system, a 30% improvement in moisture measurement accuracy can still be obtained if both the slope and offset can be adjusted in the calibration process. Currently, the Wagner 683 moisture measurement system provides an offset correction using the "Variable Sensitivity" adjustment. With conversion to digital electronics and a processor-based system, a slope and offset correction should be readily available in the near future.