DEVELOPMENT OF A NEW LUMBER UNSTACKER MOISTURE METER

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In a typical sequence of operations after drying, lumber is cooled, unstacked, and planed. Between the unstacker and planer there is an opportunity to measure the lumber moisture content. The unstacker normally feeds a transverse chain where the boards can be singulated for measurement of individual board moisture contents. Beyond the measurement point, a dropout can be provided for "wets," which can be subsequently redried or simply sold in a "below grade" category. The moisture content data can also be analyzed to track and evaluate the kiln drying process.

One of the major uses of an unstacker moisture meter is to reduce degrade from overdrying. In studies made between 1972 and 1981 on western hemlock, Douglas-fir, and southern pine, researchers identified a potential opportunity of $4/m^3 ($6/10^3 BF) if degrade from overdrying were reduced to an acceptable level (Steinhagen 1979). This did not include potential benefits associated with reduced planer downtime, kiln diagnostics, and loss in value of excessive wets. It does assume active operator response to the processed data in effecting changes to reduce the degrade.

The need for a new unstacker moisture meter was based on analysis of operating deficiencies of an existing meter developed by Weyerhaeuser. This meter used parallel plates (two plates per head) in multiple-head installations. Principle of operation [covered by patents 3,354,388 (1967); 3,339,137 (1967); and 3,593,128 (1971)] involved a balanced bridge measurement of impedance at 10 kHz in which the output from the two heads remained relatively constant with vertical position of the board. The distance of a board from a head is critical since the electric field will decrease in proportion to the distance. Small amounts of warp can cause large measurement errors. Design of the system was such that resistive reactance was the major variable sensed as moisture content changed. These reactances are similar in magnitude to the resistance measured with a hand-held DC moisture meter.

An assessment was made of the unstacker meter in terms of improvements that could be made, which led to a new design using a single plate head. Table 1 outlines the characteristics of the old two-sided head system and the perceived requirements for a new system. The original design suffered from several major deficiencies which affected precision, repeatability, and moisture content range. For example, the upper head quite often was damaged by surges of lumber and became misaligned with the bottom head. The moisture content range was limited (about 12 to 24% MC) because of the frequency used and circuit design. The output was analog voltage only and not calibrated for moisture content. The head circuitry and physical design caused problems with static electricity during low relative humidity periods, excessive reaction to condensation on the heads at high relative humidities, and drift from temperature sensitivity of electrical components. The design and configuration of electrodes caused differences in output as the board width or thickness changed. There were no means of adjusting or selecting different corrections when the species was changed. Wood temperature has a significant effect on reactance and no means of correction were available. Also, marking or dropout of wets was determined by the highest reading head, with no practical means of processing head data.

Design of the new meter concentrated on reducing or eliminating these deficiencies as well as developing a system which would permit data acquisition and processing, and have a simplified means of calibration, standardization, and maintenance. The new meter uses a single-sided fringe field, permitting operation with sensor heads below the chains. Board height is compensated for by using two frequencies which also permit extension of the moisture content range. The meter also has compensation for species and temperature. The gauge can be operated as a "stand-alone" unit or as an element in a higher level system.

Functional Description

Figure 1 shows the conceptual system. As a board moves over the heads, it activates length limit switches which indicate the number of active heads. The board must fully cover the head in order for that value to be processed. The reset switch is energized as the board clears the heads which initiates two actions: processing of the head signals and automatic rezeroing of the heads. The temperature sensor provides input of ambient air temperature and an encoder is used to synchronize downstream events (such as spraying or gate actuation). In Figure 2, the functions are shown schematically. Two sinusoidal waveforms of 312.5 Hz and 10.0 kHz are used to generate an electrical fringe field. When lumber passes through the field, its resistance and capacitance are measured together with the gap capacitance. The lumber causes an imbalance in the bridge circuit which is amplified and the two AC components are separated. Each of these AC signals is then detected to yield two time-varying DC signals. Sample and hold is accomplished by the microprocessor. The microprocessor then calculates a temperature-corrected MC and corrects for the selected species. If the reading exceeds a preset moisture content level, a signal produced by the microprocessor permits board dropout or marking.

If V_1 and V_2 represent the two DC voltages generated from the two sinusoidal waves, the moisture content (U) can be found from the following equation:

$$U = A(T) + B(T)V_1 + C(T)V_2 + D(T)V_1V_2$$

U represents the moisture content for coastal Douglas-fir. A(T), B(T), C(T) and D(T) represent temperature compensating coefficients. T is temperature (°C).

The temperature corrected constants can be found through the following equations:

$$A(T) = A_o + A_1T$$

$$B(T) = B_o + B_1T$$

$$C(T) = C_o + C_1T$$

$$D(T) = D_o + D_1T$$

The moisture content for a selected species (U_x) is calculated by:

$$U_x = A + BU$$

where A and B are species correction constants.

The board average moisture content is then found by executing a weighted average of all head readings. The weighting reduces the influence of an excessively high head reading due to a small wet spot.

Accuracy Evaluation

The prototype meter was tested under mill operating conditions to obtain accuracy on kiln-dried western hemlock dimension (2x4). The specific objectives were to define indicated moisture content accuracy vs. ovendry tests, make readings on the same sample with a Delmhorst to understand the comparative accuracy, and evaluate possible sources of error. Measurement error from a single side of the board and effect of wet spots on average moisture content were also tested. Moisture content accuracy was determined by marking board areas which would be sensed by the three heads. The test matrix is given in Table 2. Each section area was measured four times with a Delmhorst G22 with two 10-mm pins. After the boards were run over the unstacker meter heads, these sections were cut out and ovendried. The effect of wet spots on meter accuracy was serious since one very small spot could dramatically shift the average value for three heads. Therefore, a weighting algorithm was developed to reduce the effect of extreme values on the average:

$$U_o = \frac{1}{n} \sum_{i=1}^{n} U_i$$

$$U_j = \sum_{i=1}^{n} w_{ij} U_i \Big/ \sum_{i=1}^{n} w_{ij}$$

$$\text{and } w_{ij} = 1/(1 + |\Delta U_{ij}|), \ \Delta U_{ij} = U_i - \overline{U}_j$$

U_j represents the jth value as defined arbitrarily by $|\overline{U}_j - \overline{U}_{j-1}| \leq 0.1$.

Results and Discussion

Figures 3, 4 and 5 show the MC readings obtained with a single Delmhorst reading per board (Figure 3), average value of 12 Delmhorst readings (Figure 4), and average values from the unstacker moisture meter (Figure 5). These data are summarized in Figure 6, where the statistical variability of the Delmhorst is graphically compared with the unstacker moisture meter. The key result is that seven Delmhorst readings are required to obtain the same average MC as a three-head unstacker moisture meter system. About one half this number of Delmhorst readings are required to equal the single head accuracy. The statistical results are given in Table 3. In summary, a single pass of a board (average of three heads) gives a variance of ± 1.3% MC compared with one reading per board of ± 2.1% MC with the Delmhorst.

For the 30 boards which had been passed over the heads to obtain readings from both faces, data were analyzed to determine if the unstacker moisture meter biased the reading toward the face of the board nearer the head. It was not anticipated that there would be a significant difference in MC of the board faces (as measured to 10 mm depth on each face with a Delmhorst). Table 4 shows that there was a measured difference of nearly 1% MC with the Delmhorst at the 95% confidence level. However, the unstacker moisture meter measured a smaller difference (0.3% MC as compared with 0.9% MC for the Delmhorst), which would not be sufficiently large to affect the system accuracy. It appears that the unstacker moisture meter substantially averages the cross-sectional variation in MC.

Repeatability for the unstacker moisture meter was tested by pooling all the data and determining the standard deviation for a single pass: 0.68 for the three-head average and 0.79 to 0.82 for a single head. These values represent coefficients of variability at 16% MC of about 4 and 5%, respectively, which is within the desired 5% CV for the meter.

The weighting algorithm was tested by simulating data representing a wide range of upsets from wet spots or other possible combinations (Table 5). The first three cases represent increasing levels of MC sensed at head #4 only. U_0 is the initial, unweighted value. The algorithm reduces the influence of a single head as that value increases. Iterative values (1 ... ∞) are given, with the underlined value representing the final iterative number based on the endpoint criterion selected. Case 4 shows the influence of a single reading in the opposite direction (6% MC). The last case (12, 13, 30, 30) is one in which the board should probably be rejected based on typical grading procedures. Since lower, but excessive MC levels at heads 3 and 4 could possibly give an acceptable weighted average, a new criterion was added: when any two (or more) heads give readings above the acceptable level, the board is rejected.

Conclusions

The following was concluded from the study on the prototype, single-sided meter:

1. MC range is comparable to that of a DC conductance meter (6% to fiber saturation point).
2. Accuracy for the three-head average MC is equivalent to seven hand-held meter readings per board.
3. Repeatability is within 1% MC.
4. An average value is obtained for boards having slightly different MC on each face.
5. Weighted average algorithm satisfactorily compensates for species having residual wet streaks.

Literature Cited

Perry, W. D. 1967. Moisture determining apparatus having adjacent electrode pairs driven out-of-phase. Patent No. 3,339,137 (August 29).

Perry, W. D. 1967. Method for measuring the moisture content of wood. Patent No. 3,354,388 (November 21).

Perry, W. D. 1971. Moisture content measuring system employing a separate bridge circuit for each sensing electrode thereof. Patent No. 3,593,128 (July 13).

Steinhagen, H. P. 1979. Economic opportunity analysis for developing an in-kiln moisture meter. In Proc. 30th Annual Meeting, Western Kiln Dry Clubs, West Coast Dry Kiln Association, Coeur d'Alene, ID.

Table 1. Characteristics of the original and new versions of the unstacker moisture meter.

Wood Variables	Original Two-Plate	Prototype Single-Plate
MC range (% MC)	12-24	8-27
Variability (CV, %)*	10	5
Species correction	None	Selectable
Density effect	None	None
Temperature effect	Yes	Corrected
Size effects: Thickness	Yes	Yes (below 35 mm)
Width	Yes	Slight (below 150 mm)
Length	Yes	No
Physical/Mechanical Design		
Contacting	No	No
Exposure	Upper head	None - below chain
Board singulation	Required	Required
Environmental effects: Temp	Yes	No
RH: Low (static)	Yes	No
High (condens)	Yes	No
Output		
Readout	Analog voltage	Digital MC
Marking/redry-dropout	Yes	Yes
Data acquisition:		
Capability	No	Yes
Option	No	Yes
Operation		
Standardization	No	Yes
Internal diagnostics	No	Yes
Drift correction	No	Yes

*Relative to about 10% for hand-held conductance meter.

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Table 2. Experimental design for the study. Boards were 2x4 western hemlock of 5-m (16-ft.) length. Sections were approximately 700 mm long, the corresponding dimension of the heads.

Boards:	30
Sections:	3/Board
Delmhorst Readings:	4/Section/Face
Unstacker Readings:	Each Head/Pass
Passes:	8 (4/Face)
OD Values:	1/Section

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Table 3. Unstacker and hand moisture meter regression curve accuracies against ovendry MC for 60 values (30 boards, 2 faces).

Section (Head)	Unstacker Meter		Hand Meter: Four Readings/Section		Hand Meter: One Reading/Board	
	R^2	S	R^2	S	R^2	S
A	0.75	1.60	0.60	2.22		
B	0.76	1.49	0.72	1.67		
C	0.65	2.14	0.74	1.72		
Average	0.81	1.26			0.60	2.08

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Table 4. Statistical test ("t" test) for differences in moisture content readings between faces of 30 boards.

	Head 1	Head 2	Head 3	Average
Delmhorst Meter				
Mean, side 1	12.3	12.2	12.8	12.5
Mean, side 2	13.1	13.4	13.2	13.4
Standard deviation*	1.77	1.87	1.85	0.99
t-value	3.29	4.76	3.70	7.28
Significance level (%)	95	95	95	95
Unstacker Moisture Meter				
Mean, side 1	11.4	11.9	12.9	12.0
Mean, side 2	11.8	12.1	13.2	12.3
Standard deviation*	0.78	0.79	0.82	0.68
t-value	4.15	1.63	2.92	3.81
Significance level (%)	95	90	95	95

*Pooled for both side readings since variation was not significant.

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Table 5. Simulated MC data for response of weighting algorithm. Underlined numbers represent final value obtained.

Head No.									
1	2	3	4	$\bar{U}_o$*	$\bar{U}_1$	$\bar{U}_2$	$\bar{U}_3$	$\bar{U}_4$	$\bar{U}_{\infty}$
12	13	14	17	14.00	13.80	13.72	13.69	13.67	13.
12	13	14	20	14.75	14.05	13.85	13.79	13.76	13.
12	13	14	30	17.25	14.99	14.14	13.91	13.85	13.
12	13	14	6	11.25	11.95	12.15	12.21	12.24	12.
12	13	30	30	21.25	21.25	21.25	21.25	21.25	21.

*Unweighted average

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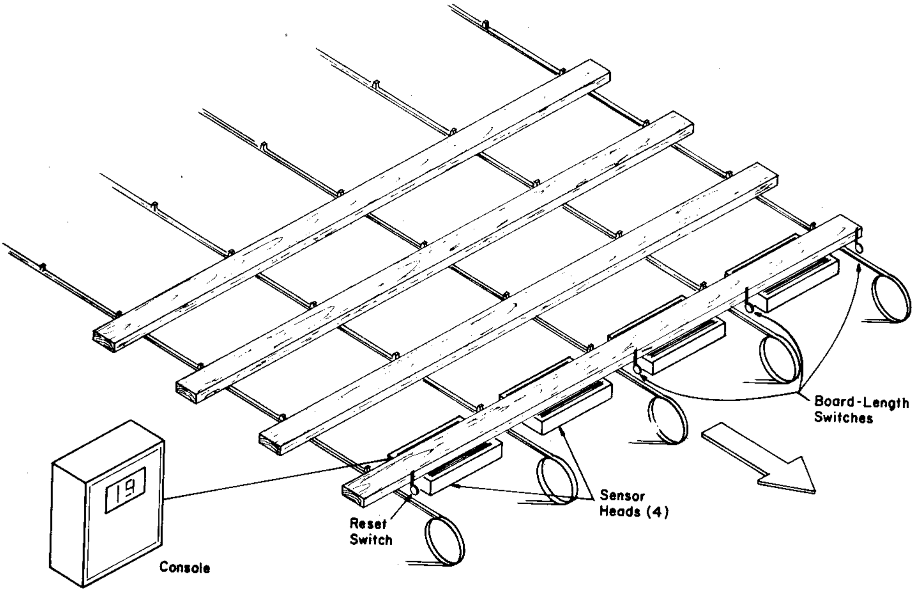

Figure 1. Conceptual design of the lumber unstacker moisture meter.

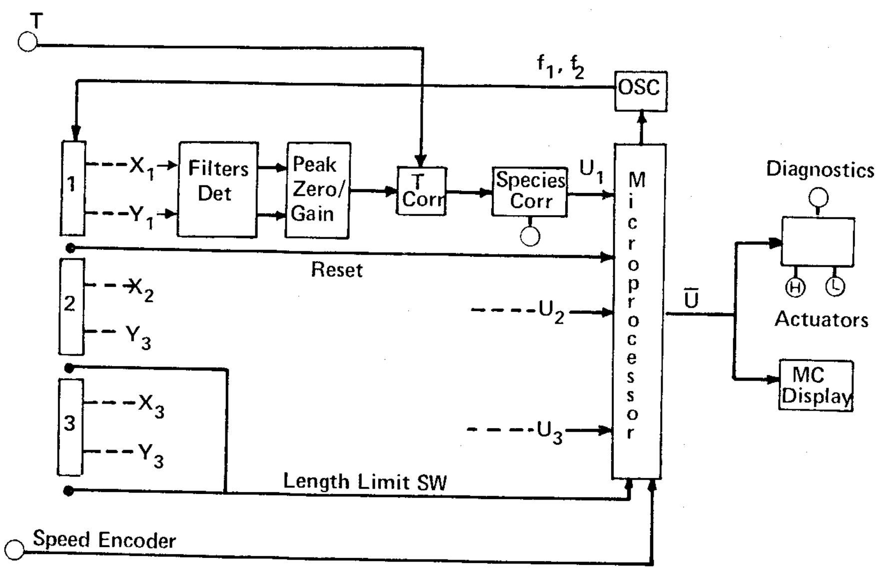

Figure 2. Functional block diagram of the lumber unstacker moisture meter showing a three-head system. U_1, U_2 and U_3 are species- and temperature-corrected moisture content values from the heads.

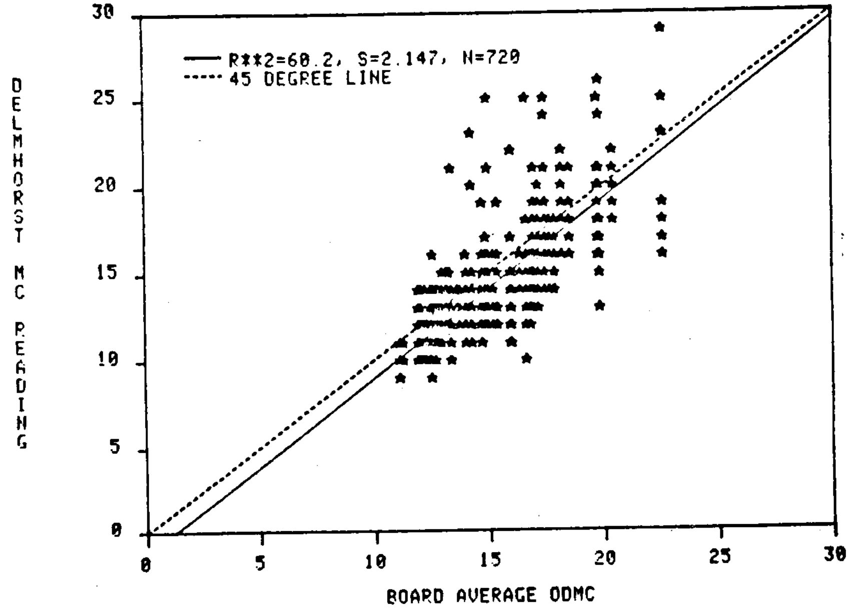

Figure 3. Individual Delmhorst moisture meter readings (Model G22 with two 10-mm pins). The 720 values represent 4 readings/section, 3 sections/board, and 2 faces/board on 30 boards. The solid regression line is slightly offset because of lack of proper species correction.

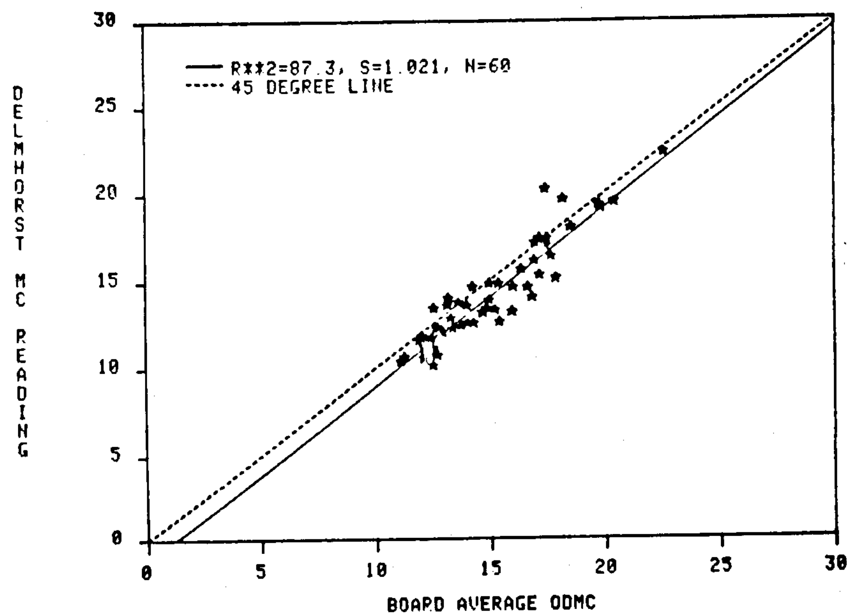

Figure 4. Average of 12 Delmhorst readings per board from the data in Figure 3. The 60 values represent 2 faces/board on 30 boards.

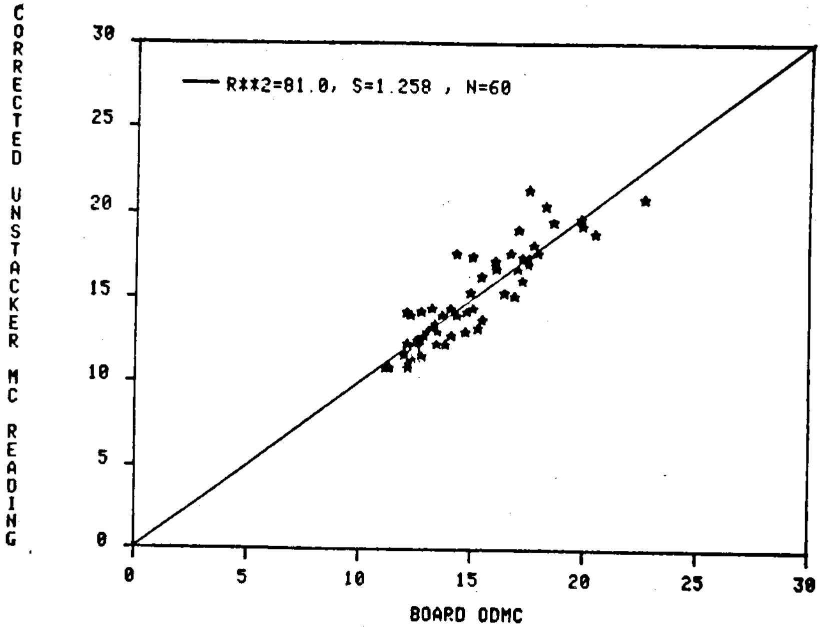

Figure 5. Average unstacker moisture meter values from the three-head prototype system corresponding to the same boards and data in Figures 3 and 4. The 60 values represent 2 faces/board on 30 boards. Weighted-average algorithm was used to determine averages.

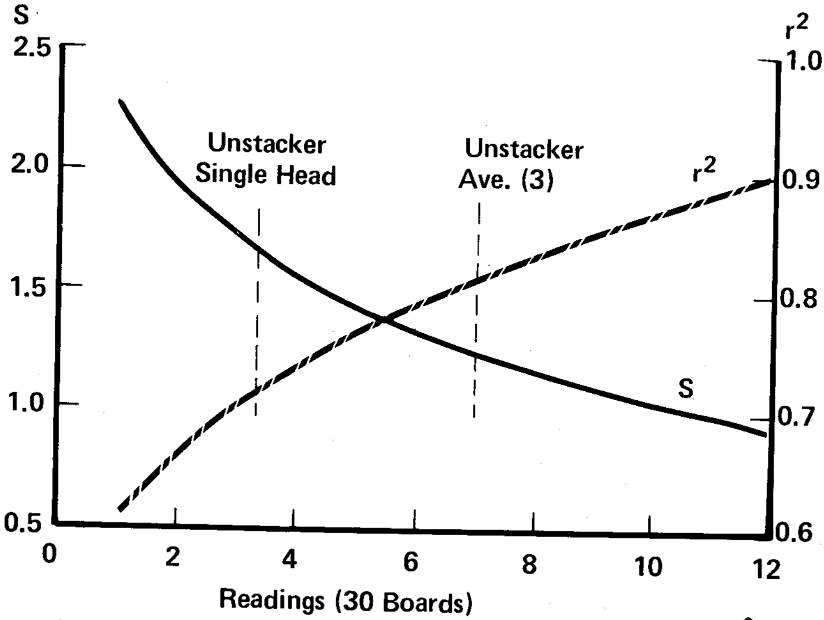

Figure 6. Standard deviation (S) and regression coefficient (r^2) for the Delmhorst readings, shown as number of readings per board. Vertical dashed lines represent the comparable values for a single head and average of three heads of the unstacker moisture meter.