ACCURACY OF A CAPACITANCE-TYPE AND THREE RESISTANCE-TYPE PIN METERS FOR MEASURING WOOD MOISTURE CONTENT

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ABSTRACT

The moisture content (MC) of 441 wood samples from 30 batches and 14 species was estimated using 1 capacitance-type meter (Wagner L612) and 3 resistance-type pin meters, and compared to ovendry MC. The L612 was the most accurate. The pin meters, whose data were corrected accurately for wood temperature, gave similar results to each other. The results were largely unperturbed by the choice of user settings for species/wood density. The basic (residual) variability of meter readings was similar for the two meter types but the pin meters had a stronger tendency to over- or underestimate MC depending on the batch. In contrast to the pin meters, the L612 was nondestructive, and quick and easy to use.

Capacitance-type wood moisture meters infer moisture content nondestructively from a volume of wood immediately below a sensor plate in the base of the meter. Such meters are sometimes said to be less accurate than the more traditional resistance-type meters, in which pin electrodes are driven into the wood. However, a recent unpublished report by the Swedish Testing and Research Institute concluded that, under practical conditions, a Wagner capacitance-type meter was more accurate and convenient to use than a resistance-type pin meter,[1] and a further report,[2] summarized in this paper, reached similar conclusions.

In this paper the accuracy of the Wagner L612 capacitance-type meter is compared with that of three pin meters in timber stored under industry conditions in England.

MATERIALS AND METHODS

Data were collected from three woodyards in England in the summer of 1998: Timbmet Ltd., Oxfordshire; Atkins and Cripps Ltd., Bilston; and Wood Bros. Ltd., Hertfordshire. A total of 441 pieces were sampled from 30 batches (parcels) in 14 species. All batches had been stored under shelter in conventional industry conditions except for two batches that had been stored outdoors. The dataset is described in **Table 1**.

The capacitance-type Wagner L612 was compared to three resistance-type meters: Protimeter Digital Timbermaster, Gann Hydromette H35, and Delmhorst RDM-2S. The pin meters used were new at the beginning of the study and all were equipped with hammer probes with sliding handles and insulated pins. The Protimeter was also equipped with a probe for measuring wood temperature. If applicable, meters were calibrated and battery-checked at the beginning of each working day.

One sample was cut per piece, at 18 cm and 30 cm from one end. Within 15 minutes, samples were weighed to the nearest 0.1 g, sample dimensions were measured to the nearest 0.1 mm, and the meter readings (MR) of the four meters were recorded. Pins were driven in along the grain, giving parity in the sampling, and the three pin measurements were about 1 cm apart from each other across the grain largely in the center of the Wagner measurement area.

All pieces were ovendried to constant weight at approximately 103°C for 2 to 4 days. They were then weighed, ovendry moisture content (MC) at the time of meter measurement was calculated, and specific gravity (SG) was converted to the U.S. standard (ovendry weight and volume at 12% MC) using a standard formula.

[1] Kemmsies, M. 1998. Comparative testing of Wagner L612, electrical resistance meters, and the ovendry determination of wood moisture content on Norway spruce and Scots pine. Report 97B2,1983. Wood Structures and Materials. Swedish National Testing and Research Inst., Borås, Sweden.

[2] Wilson, P.J. 1998. Comparison of the Wagner L612 and three pin meters, Europe 1998. Report W.11.98. Brickearth Data, Kent, U.K.

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Settings are required for wood temperature and species in the pin meters and for species/SG in the L612. Wood temperature was estimated from at least three samples per batch, using the Protimeter probe, and all pin meter data were corrected for this mean temperature per batch using the tables of corrections supplied. For all meters, species/SG settings were not always available in the menus/documentation provided. Alternative species were chosen on the basis of similarity in relationship or species SG. The settings used are shown in **Table 2**.

TABLE 1. — Description of data.

Species	Batch	*n*	Origin
Douglas-fir	4	60	Oregon
Yellow pine	3	45	USA
W. redcedar	1	15	Br. Columbia
W. hemlock	1	15	Br. Columbia
Eur. oak	3	45	England
Hard maple	1	14	N.Y. State
White oak	2	30	Pennsylvania
White ash	2	30	Carolinas
Red alder	1	14	Oregon
Eur. beech	5	71	Romania
Utile	2	30	W./C. Africa
Sapele	3	45	W./C. Africa
Sepatir	1	12	S.E. Asia
Idigbo	1	15	Ivory Coast

TABLE 2. — Settings used for the various species/meters.

Species[a]	Wagner	Protimeter	Gann	Delmhorst
Douglas-fir (DF)	DF	DF	DF	DF*[b]
S. yellow pine (SYP)	SYP	SYP	SYP	SYP*
W. redcedar (WRC)	WRC	WRC	WRC	WH
W. hemlock (WH)	WH	WH	WH	WH
Eur. oak (EO)	Custom[c]	EO	EO	R. oak
Hard maple (HM)	Sugar	Sugar	Hard	Sugar
White oak (WO)	WO	WO	WO	WO*
White ash (WA)	WA	WA	WA	WA*
U.S. alder (AL)	AL	Bla. pop.	AL	Y. pop
Eur. beech (EB)	Custom[c]	EB	EB	R. oak
Utile (UT)	Custom[c]	UT	UT	Ch.*[c]
Sapele (SA)	SA	SA	SA	Ch.*[c]
Sepatir (SE)	SE	Meranti	SE	Af. ma.
Idigbo (ID)	True ma.	Af. ma	ID	Af. ma.

[a] R. oak = red oak; Sugar = sugar maple; Bla. Pop. = black poplar; Y. Pop. = yellow-poplar; Ch. = cherry; Af. ma. = african mahogany; True. ma. = true mahogany.
[b] In rows marked with an asterisk, settings in all meters were specifically correct.
[c] Settings specifically recommended by the manufacturer. For Custom, the SG setting was 0.55.

TABLE 3. — Overall accuracy of four moisture meters, the capacitance-type L612 and three resistance-type pin meters, as number and percentage of MRs within 2, 1, and 0.5 percent of MC (MR ± 2%, MR ± 1% and MR ± 0.5%) in 441 pieces, together with the results of χ^2 tests comparing the pin meters (Pin), and the L612 and pin meters combined (612 vs. pin), with 2 and 1 df, respectively.[a]

	L612	Pin meters			Comparisons (χ^2)	
		1	2	3	Pin	612 vs. pin
No. of MRs	363	308	311	330	3.2 ns.	18.9**
MR ± 2%	82.3	69.8	70.5	74.8		
No. of MRs	222	195	193	197	0.1 ns.	4.8*
MR ± 1%	50.3	44.2	43.8	44.7		
No. of MRs	119	127	112	129	2.0 ns.	0.1 ns.
MR ± 0.5%	27.0	28.8	25.4	29.3		

[a] * = p = 0.000; ** = p = 0.028; ns.= not significant.

Accuracy is analyzed by Levene's Test of homogeneity of variance, using the absolute deviations (ignoring sign) of MR from MC. This test is approximate but insensitive to any positive kurtosis.

RESULTS

OPERATIONAL ACCURACY

The proportions of MRs within 2, 1, and 0.5 percent of MC in the four meters are shown in **Table 3**.

The L612 was more accurate overall than the pin meters combined at the levels of accuracy MR ± 2 percent and ± 1 percent of MC, but there was no evidence of difference at MR ± 0.5 percent of MC.

The frequency distributions of the individual deviations of MR from MC (n = 441) for the four meters are shown in **Figure 1**. The maximum height of the distributions is similar, reflecting the similar result at the highest level of accuracy, while spread/asymmetry appear to be least in the L612. This was tested by Levene's test.

Table 4 shows that Levene's test was significant and that virtually all of the difference can be attributed to the lower variability of the L612's absolute deviations.

The pins of all meters were driven in along the grain, although the Gann meter is designed for cross-grain measurement. This is expected to have inflated MR by up to 2 percent at 20 percent MC, with diminishing effect down to 10 percent MC. All Gann MRs were adjusted by the overall mean bias (**Table 5**) to give zero overall bias, but the adjusted MRs were no more accurate[2].

BIAS AND RESIDUAL VARIATION

The individual deviations (MR – MC), which give operational accuracy, are composed of 1) bias; and 2) residual variation. Batch-basis bias (the majority) is defined as [batch mean MR minus batch mean MC] and is shown in **Table 5**.

Overall bias (across batches) was low to moderate in all meters (**Table 5**). However, the three pin meters all had relatively high positive bias in their worst batches, and the mean absolute batch bias (n = 30) in the pin meters combined was 44 percent higher than in the L612. Most of the difference was due to the frequency of outlying batches. Batch bias exceeded ± 2 percent in 1 of 30 batches in the L612 but in 9, 8, and 7 batches in the three pin meters. Comparing these proportions individually gave: $\chi^2 = 7.8$, 3 df; $p = 0.050$, or combining the pin meter proportions: $\chi^2 = 6.1$, 1 df; $p = 0.013$.

The residual variation in MR, which is determined by the predictive models employed in the meters as well as by variability in MC, can be expressed as the absolute deviations of MR from MC after bias has been removed:

Indiv. residual deviation = Abs.[(MR – MC) – (Batch mean bias)]

This variation was compared to the variation in MC (**Table 6**), excluding three outlying data that gave high deviations in all meters.

The L612 data had the highest residual variation (Abs.mean, **Table 6**) although this difference, tested with Levene's test, was not significant ($F = 2.5$; 3,1748 df; $p = 0.060$). It is clear that the greater accuracy of the L612 was largely due to its relative freedom from high batch bias.

Settings

Settings, shown in **Table 2**, were exact in 17 batches ($n = 255$) and approximate in 13 batches ($n = 186$). Accuracy in these two groups is shown in **Table 7**.

Exact settings gave slightly higher accuracy than approximate settings: 48 percent MR ± 1 percent MC compared to 43 percent (**Table 7**). The L612 was more accurate than the pin meters combined when settings were exact (56.1% compared with 45.2% MR ± 1 percent MC; χ^2, 1 df = 8.6; $p = 0.003$), but there was no significant difference when settings were approximate (42.5% compared to 42.8%).

Discussion

The L612 was more accurate than the pin meters combined. The pin meter data were adjusted for temperature more exactly than is usual in practice, and the results were not unduly perturbed by other sources of extraneous variation such as choice of user-settings for species/SG. The difference in overall accuracy was largely attributable to a greater tendency to high batch-origin bias in the pin meters, when MR was a consistent over- or underestimate of MC, depending on the batch.

Batch-origin variation is an important and probably inevitable feature of the industrial context. In pin meters, contributory factors may include error in estimating wood temperature or in driving the pins in to the recommended 1/3 depth, and variation in wood anatomy or ionic mineral content. The L612, which has a large sensor area and sample volume, may be affected by the flatness of the surface or piece thickness, although other Wagner models have smaller sample areas/volumes if desired. In both meter types, any perturbing effect of surface moisture can be largely evaded by using insulated pins or, in the L612, by measuring the undersides of pieces of interest.

In the present study, the steepness of the moisture gradient from the surface of the piece to the interior, which is also likely to vary by batch, was probably

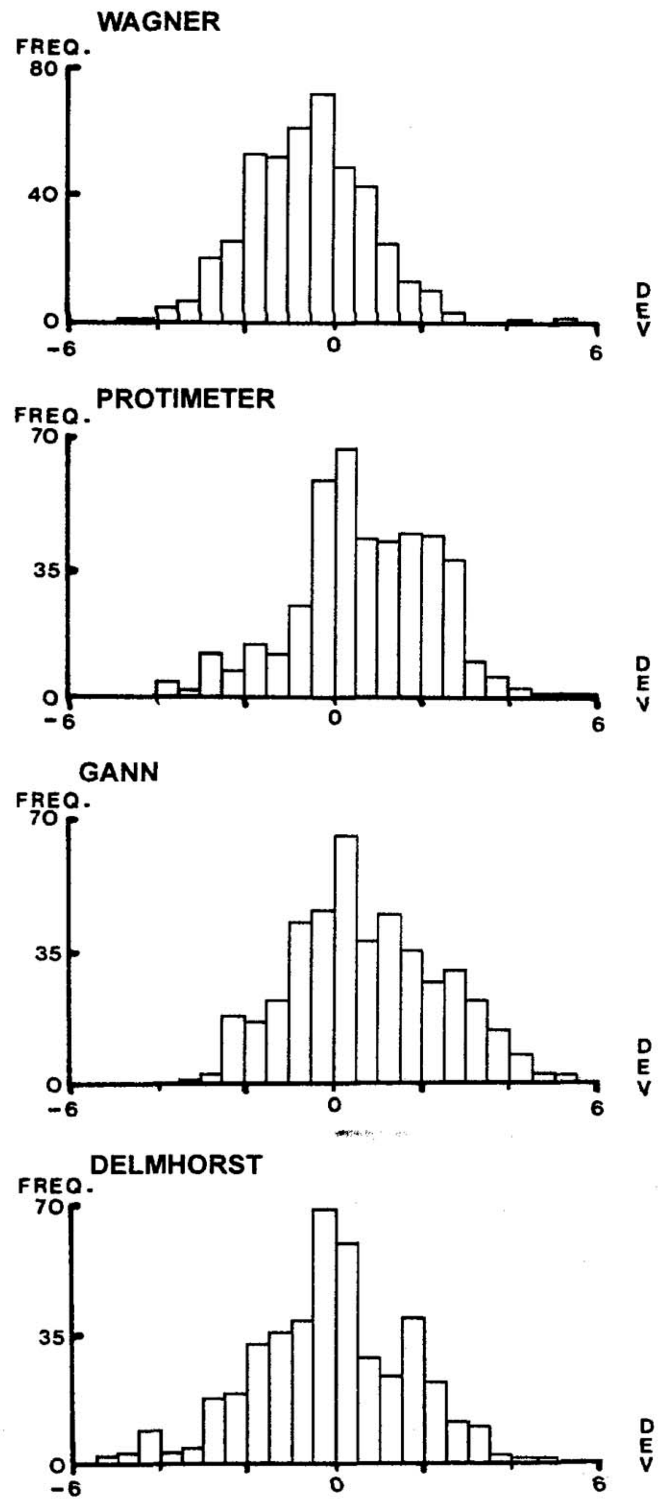

Figure 1. — Frequency distribution of deviations of meter reading (MR) from moisture content (MC) in four moisture meters ($n = 441$). Interval width = 0.5 percent.

TABLE 4. — The mean absolute individual deviations of MR from MC (n = 441) in four meters, together with details of Levene's test.

	L612	Pin meters 1	2	3
Mean abs. deviation	1.257	1.440	1.521	1.437
Levene's test:	df	MS	F	*p*
Meter	3	5.4824	3.1	0.027
Error	1760	1.781		

TABLE 5. — Bias (batch mean MR – batch mean MC) in 30 batches and 4 moisture meters. The maximum positive and negative bias is shown, together with the mean bias (n = 30) and absolute mean.

	L612	Pin meters 1	2	3
Negative	-2.52	-2.03	-1.47	-5.26
Positive	1.40	3.00	4.40	2.89
Mean	-0.46	0.79	0.84	-0.20
Abs.mean	0.88	1.33	1.22	1.27

TABLE 6. — Summary of maximum positive and negative individual residual deviation in MC (MC – batch mean MC) and in MR [(MR – MC) – (batch mean bias)] in n = 438. The absolute mean residual deviation (Abs.mean) is also shown.

	MC – BMC	L612	Pin meters 1	2	3
Max. negative	-3.88	-3.16	-3.02	-2.95	-2.92
Max. positive	4.41	4.99	4.04	3.94	3.32
Abs.mean	0.675	0.744	0.656	0.706	0.641

TABLE 7. — Accuracy of four moisture meters as number and percentage of MRs within 1 percent of MC (MR ± 1%) depending on whether the meter settings were exact (17 batches) or approximate (13 batches).

Species	L612	Pin meters 1	2	3	No. of pieces
Settings exact					255
No. of MRs	143	136	99	111	
MR ± 1%	56.1	53.3	38.8	43.5	
Settings approximate					186
No. of MRs	79	59	94	86	
MR ± 1%	42.5	31.7	50.5	46.2	

relatively important. This source of variation is likely to perturb the MRs of both meter types, although the L612 MRs, which integrate MC from the surface to up to 25-mm depth, are likely to be more stable.

In a specialized context, the pin meter pins could be driven in to different depths, giving a different reading at each and thus revealing the steepness of any moisture gradient. However, in practice, it is not feasible to integrate such pin meter MRs into a composite estimate of MC because it would be too complicated and time consuming. Even the basic procedure to record 1 pin meter MR takes an estimated 4 to 10 times longer than for the L612.[1,2]

The L612 is insensitive to wood temperature, whereas in practice the necessary correction of pin meter MRs is prone to substantial error. A guess based on daytime air temperatures can be misleading (for example when nights are much colder), and there may also be appreciable individual-piece variation (e.g., in sunny weather).

Pin meter MRs tended to drift downwards, by up to 1 percent MC over 30 seconds. In this study, MRs were recorded consistently, a few seconds after the pins were driven in, but in practice this source of error could be appreciable. The downward drift may have been due to a slight initial surge in conductivity or to the progressive relaxation of the wood around the pins, decreasing the contact area (and increasing electrical resistance) with time. Consistent with this possibility, the meter with the most obtuse pin tips also gave the most unstable readings.

The L612 is nondestructive and was relatively easy to use. In the pin meters, the violent operation of the hammer probe shocks the user's limb and equipment, and the connecting cable (as well as the edge of the palm) are easily pinched. The pins damage the wood by leaving holes and also by snapping off from time to time.

Conclusion

In industry conditions, in timber stored under shelter, the capacitance-type L612 performed better than three pin meters combined. It was more accurate, and quicker and easier to use. Further accuracy comparisons would be of interest, for example in outdoor-stored, recently kilned, and laboratory-conditioned timber.