Moisture monitoring system based on a remote moisture sensor

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Abstract

The moisture monitoring system being developed provides a network of monitoring cells, centrally monitored, to give early warning of potentially damaging failures of building components, generating high and persistent moisture levels, which are known to cause decay and damage to timber and masonry. The most critical aspect of system design is the useful range of the sensors, and their performance and reliability are crucial to a low maintenance installation and long-term customer satisfaction.

The paper describes the development of a new moisture sensor to meet the requirements with respect to accuracy; no species calibration is needed. The sensor consists of two pairs of parallel electrodes, equivalent to a network of six resistances, providing the potential for measuring moisture gradients. Electrodes are embedded with a cylindrical, high durability wood buffer. Several existing measurement techniques are evaluated. Performance of a prototype used in connection with a datalogging system is described. Results demonstrate the possible benefit to the construction industry in all situations where there is the need for an accurate long term measurement of the moisture content (MC) of timber, for example, in purchase, treatment, construction and surveying.

Key words: Moisture sensors, timber, instrumentation

1 Introduction

Moisture is associated with a range of problems in timber. For example, warping, shrinkage and distortion in service can occur where substantial variations exist between the installation and final moisture content (MC) [1]. The resistance to decay is severely affected by the MC of timber as the colonisation of fungi is strongly dependent on the MC. For example, if the MC is above around 25% the probability of fungal decay increases dramatically, especially where the timber is classed as "non-durable" [2]. Hand-held moisture meters are frequently employed for monitoring MC, where individual readings are taken at selected points, these being limited to surface or near surface measurements. For resistance type instruments, if species and temperature corrections, grain orientation and possible moisture gradients are ignored the measured values could suffer large errors.

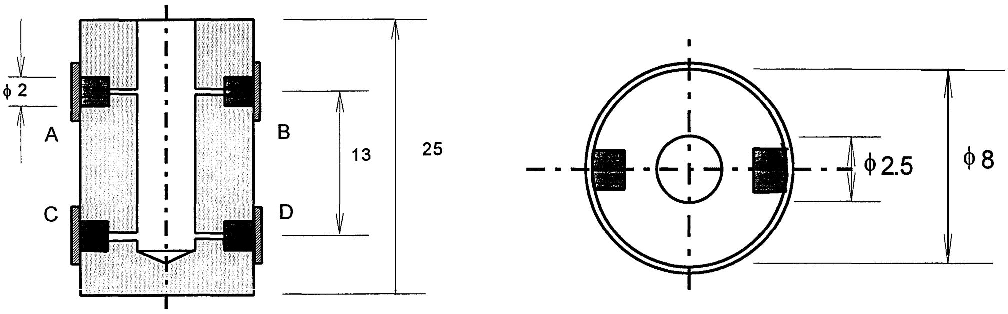
For large and/or inaccessible regions, moisture sensors with long term reliability, small enough to minimise disruption are needed for continuous monitoring. Extensive literature searches reveal that various types of sensor are in existence. [3] and [4] describe small wood sensors (approximate 4×4×15 mm). These are low-cost and easy to produce. In trials with similar sensors, the authors of this paper found that the main problem is in ensuring long-term reliable contact between the conductors and the wood surface. Inter-sensor variations have also been observed to be substantial. [5] describes a composite sensing probe able to measure resistance using stainless-steel rings at various depths in wood. However, the construction of these sensors appears to be involved and the probes are probably not inexpensive.

Sensors designed and produced by the authors' have the following characteristics: durable, low-cost, easy to produce and have small inter-sensor variability although individual sensors can be easily calibrated against oven-dried moisture contents. Small screw-type conductors ensure efficient long-term contact with the wood. Screw-type electrodes were employed very effectively in a previous project [1].

2 Moisture Monitoring System

2.1 Sensor Structure

Sensors employ wood buffers made from several species to ensure long term durability, 8 mm in diameter and 25 mm long. Two pairs of silver painted brass screw-type electrodes are inserted into the wood buffer 13 mm apart along the buffer grain (see Figure 1). A hole, 2.5 mm in diameter, allows the insertion of wires for connection to the electrodes. The 7-gauge shielded leads carry the signals over 4 m to the amplifiers. The isolating material (1 mm width) covers the electrodes to ensure that the electrodes do not touch the sample tested. The majority of the buffer is exposed inside the monitoring material in order that the buffer can reach equilibrium quickly. This sensor is referred to as GD1 hereinafter. In use, although the buffer maybe contact the test sample, this does not noticeably affect the final readings because the resistance of timber strongly depends on the contact of electrodes and buffer. For equilibrium moisture condition, the resistance of the buffer (R_b in Figure 2) is very much less than that of the sample tested (i.e. R_s in Figure 2), that is, R_b<<R_s, therefore, overall the resistance $R=R_b//R_s \cong R_b$.



(a) Side Section (b) Top view

Figure 1 Sensor model; dimension in mm

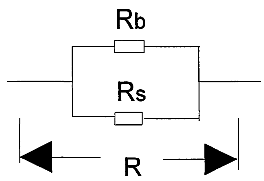


Figure 2 Resistance relation between buffer and sample tested

A range of wood species for the buffer have been carefully selected based on the application purpose. Buffer species are selected based on the permeability, durability and resistivity. Generally, the priority factors chosen are high permeability and low resistivity of buffer species. But for long-term monitoring of MC, durability is high priority.

2.2 General description of the circuit

The block diagram of the circuit is shown schematically in Figure 3. Unlike the commonly used full and half bridge methods, this approach requires no intermediary (and well-characterised) high-resistance standards to bootstrap up the resistance scale. Because the moisture meter should be able to operate over a wide range of moisture contents, a logic seeking strategy to find the appropriate range has been used. In

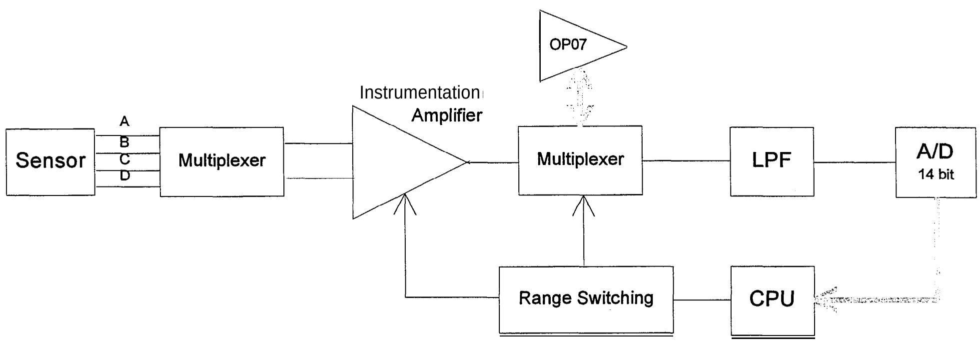


Figure 3 Schematic diagram of the moisture meter. (A/D: analog to digital converter; CPU: central processing unit; LPF: low pass filter)

Figure 3, the instrumentation amplifier has variable gain from 1 to 1 0^4. A high accuracy operational amplifier (OP07) is reserved as second-stage amplifier. These realise a practical operating range between 1kΩ and 100GΩ. Under simulated conditions, the meter measures accurately from 8 to 75 percent moisture content; in practice, however, the readings above the wood fibre saturation point should be considered only as "useful" as a resistance varies slowly with MC in this region.

2.3 Detailed considerations for improved performance

1. Species compensation

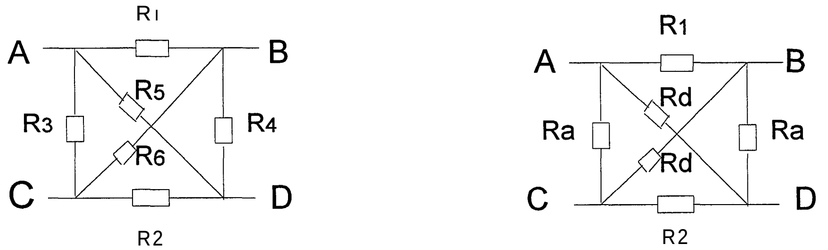
Since the wood species for the buffer in GD1 is fixed, relating resistance to wood MC can be determined in the laboratory based on oven-dried measurements of virtually identical samples. For this reason, no species correction are needed for measurements in varying samples. The final MC readings for samples tested can be determined from the relationship established in [6]. This database will be included in the microprocessor firmware, and the reading can be transformed automatically.

2. Polarisation consideration

This system solves the problem of polarisation by using an alternating polarity test sequence. Each sequence consists of the application of a positive polarity voltage, and after an appropriate delay, measures the current; the voltage polarity is then reversed and the current measurement again after the same delay time. This is repeated for a number of cycles (usually about seven) until the user observes stable readings. The instrument then calculates the resistance based on a weighted average of the last four readings.

3. Accuracy improvement

Current moisture meters only measure MC at the point of test. The test data in next section reflects that in some circumstances there are different MC readings from two pairs of electrodes in different depth of test sample. To understand the resistance variation in different directions within the buffer, it is essential to appreciate the electrical equivalent circuit of the measurement process; this is shown in Figure 4. Refer to Figure 1 for the equivalent points on the sensor. Because both R_3 and R_4 are resistances along the buffer grain, and R_5 and R_6 are resistances between two pairs of diagonal electrodes, the following assumptions can be made: $R_3 = R_4 = R_a$; $R_5 = R_6 = R_d$. Figure 4(a) can then be further simplified, Figure 4(b). If all of resistances can be measured, the final values calculated from these resistances will be more accurate measure of MC than that from a single resistance.



(a) (b)

Figure 4 (a) Equivalent circuit diagram of GD1 sensor (b) Simplified resistance network

4. Noise reduction

Numerous sources of error relating specifically to high resistance measurements (equivalent to low moisture content) have been analysed in [7]. Results of these analyses are still germane to our present work. The two leading limiting factors for obtaining a high accuracy are leakage currents and noise. In order to limit these factors, extensive attention should be paid to correct shielding and guarding, especially of the input terminals, i.e., from electrodes to circuit. Currently, screened cable has been used to transmit the signal. Input cables are shielded throughout. PTFE substrates substitute ordinary PVC for the circuit boards, effectively reducing the leakage current through the printed tracks. Guard pins adjacent to both input connections of the instrumentation amplifier have been used to drive circuit board and input cable guards to maintain extremely low input bias current.

3 Calibration and results

At present, most moisture meters use empirical equations, for example,

$$\log [\log(R)-4]=1.009-0.0322M$$

to relate resistance, R in Ω, along the sample grain to the percentage moisture content M, at temperature 20°C [8].

Figure 5 shows the variation in the electric resistance with moisture content. The shaded area shows the region in which 90% of commercially available species fall [8]. Carl1 [3] and Skaar [8] have well explained the electrical properties of wood, and here we mainly concentrate on the behaviour of the GD1 sensor.

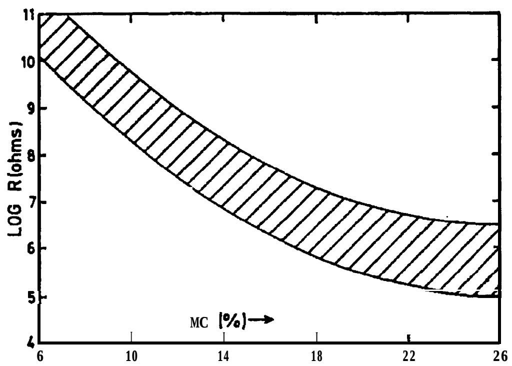


Figure 5 Electric resistance versus MC for most of commercially available wood species [8]

3.1 Comparison of three types of sensor readings

A limited calibration was carried out using timber species, Opepe and Beech, for GD1 sensor buffer. These choices of timber were dictated by the groups own particular requirements. Recalibration is necessary if other timbers are used.

Holes, 10 mm in diameter, were drilled into a number of Beech samples. The GD1s were pushed into the holes and the holes were sealed with silicon caulk to ensure that the outside atmosphere does not affect the buffer environment. Sensors were not inserted near obvious defects to ensure that the electrodes give more consistent readings. Three sensors were installed in the same conditioning chamber at 75% relative humidity (RH) and 20°C. Table 1 shows some of the MC measurements. Measurements were taken over a six month period. Although there is some variability between sensors, the fluctuation for a given sensor were less than 0.5% MC, showing long term reliability.

Table 1 Percentage MC readings from three different types of electrodes

(CT type sensor is type referred to in [3])

	Electrodes	MC
Set 1	Pin-type	14.1
	CT type sensor	11.7
	GD1 top pair	12.9
	GD1 bottom pair	12.9
Set 2	Pin-type	14.4
	CT type sensor	13.1
	GD1 top pair	12.9
	GD1 bottom pair	13.1
Set 3	Pin-type	13.7
	CT type sensor	12.8
	GD1 top pair	13.7
	GD1 bottom pair	14.1

In Table 1, the GD1 buffers of set 1 and 2 are Beech and that of set 3 is Ramin. Although the samples have not been oven-dried and we do not know the exactly final MC, it is very interesting that the readings from GD1 sensors are systematically lower compared with those from direct pin insertion. The CT type sensors consistently lower readings than the GD sensors, presumably being caused by very high contact resistance.

Pin-type electrodes and wood sensor can only reflect the MC at the depth of contacting with the samples. There is commonly moisture gradient inside the sample at any time, the average value from GD1 sensor gives more reasonable results.

The speed of moisture sorption greatly depends on the surface to volume ratio of the sensor. For the CT type wood sensors, only top end exposed to its environment, so response of wood sensor is relatively slow especially under drying conditions compared with GD1 sensor.

3.2 GD1 in specified RH

Table 2 gives a measure of MC in various RH conditions for an individually calibrated sensor. Only if an individual calibration data is available for each sensor can an "absolute" MC be resolved to the precision given in this table. However, even without an individual calibration data, the table gives the tracking sensitivity of a sensor.

Table 3 shows the MC readings based on the individual resistances of electric network in Figure 4(b). At present, the relationship between the overall MC and the resistances both along the wood grain and perpendicular to the grain are being work

Table 2 Sensor calibration, showing mean values of MC

MC % / Sensors	Percentage RH at 20°C			
	33	66	76	93
Oven-dried MC	8.48	13.50	15.12	22.5
GD1 No.1	7.78	12.34	14.60	15.84
GD1 No.2	8.00	13.52	14.94	17.42
GD1 No.3	--	11.92	14.22	15.62

out. The data in Table 3 indicate uncertainties in the MC for a given RH or calibration measurement. On average, the uncertainty between measurement from the two sensors is less than 0.3%. An investigation is on the way to estimate in the uncertainty of the "absolute" MC if individual sensor calibrations are not available. It is quite difficult to offer a universal calibration for the sensors as this will be buffer material-specific and will have fabricating uncertainty; however, other workers should have no difficulty in using the technique presented here and calibrating for their own particular needs.

Table 3 MC readings based on individual resistances defined in Figure 4(b)

	Percentage MC readings from			
Conditions	R1	Ra	Rd	R2
GD1 No.4 at RH 55%	11.7	11.7	11.1	11.4
GD1 No.5 at RH 55%	11.4	11.5	11.3	11.5
GD1 No.4 at RH 75%	15.7	15.6	15.8	13.8
GD1 No.5 at RH 75%	14.9	15.1	14.8	15.1

4 Discussion and Conclusion

The data obtained to date shows good consistency and reproducibility. However, various improvements are necessary, partly for automation of the set-up and partly to ensure high accuracy.

Early prototype sensors indicated much variability. General improvements have been made to sensors by improving machining techniques using uniform batches of materials, dimensional uncertainties and consistent sized screws. Screw electrodes are secured into precision holes for minimising contact resistance variations.

Very roughly, for every 10°C deviation of temperature from the calibration temperature of 20°C, an error of 0.5 % MC results, although the current tests have been performed at constant temperature, 20°C. Calibration over a range of suitable temperature (e.g. 0°C to 30°C) is necessary for in-situ use. Suitable thermocouple sensors will be introduced into the buffers to automate temperature compensation.

Equilibrium MC values are history dependent, i.e., the final MC depends on whether the buffer is absorbing or losing moisture. This hysteresis effect can be substantial under certain conditions, affecting the readings by typically up to 1% MC. Investigations are underway to determine procedures for compensating for this effect.

In conclusion, the sensors described provide stable readings, and the data collected indicated the reliability in the long term. By using measurements from effectively a network of resistors, results are more accurate and more reproducible.

The manufacture of electrodes is straight-forward and based on low-cost materials. Inter-sensor variation in performance is being minimised by improved machining and engineering, although there will always be slight variations between sensors caused by material variability. The sensors have the potential for detecting moisture gradients even though this facility has yet to be exploited.

5 References

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