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AUTOMATIC DATALOGGING TIMBER MOISTURE CONTENTS OVER THE RANGE 10%-50% W/W

M.J. Cunningham

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Automatic Datalogging Timber Moisture Contents over the Range 10%–50% w/w

M. J. Cunningham
Building Research Association of New Zealand

A compound technique is described for automatic datalogging over prolonged periods of timber moisture content over the range of 10% to 50% w/w. Timber moisture contents above 25%-30% cannot be reliably measured using the dc resistivity of the wood, because dc resistivity is almost constant at these moisture contents and polarization phenomena give rise to both short- and long-term drift — indeed there is a risk of irreversible breakdown due to these electrochemical reactions. While an ac vector impedance measurement is wide ranging, the impedance versus moisture content relationship is both complex and difficult to measure, particularly automatically.

The solution offered here uses 10-mm square gold plated parallel plates embedded in the timber; below 30% moisture content their dc resistance is measured; above 25% moisture content the magnitude of the ac impedance is measured. In the overlap region, 25%-30% moisture content, the moisture content is determined as a weighted mean of the dc and ac results. These probes are datalogged automatically. The driving circuitry, data transmission considerations, and computer software details are described. Limited calibration results are given, which indicate useful absolute and relative moisture readings up to about 50% mositure content.

INTRODUCTION

The Building Research Association of New Zealand (BRANZ) is interested in the rate of drying of construction moisture in the timber framing of new houses, which in New Zealand are sometimes closed in at moisture contents well above fibre-saturation. As part of a program to understand this process[1] experiments have been designed using roof specimens placed in controlled climate chambers. These specimens are extensively instrumented and the data-logged over a lengthy period; in particular it is necessary to be able to regularly and automatically log the moisture content of the timber as it dries from a very wet condition, well above fibre saturation.

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The Problem

The problem is to be able to measure and automatically log the moisture content of timber in a range of moisture contents from dry to very wet, say, from 10% to 50% moisture content by weight.

One of the simplest methods for measuring timber moisture content that lends itself to automation is to measure the dc resistivity of the wood. This is a strong function of moisture content for drier timber (less than, say, 20% moisture content by weight) and a weak function of temperature. However, for moisture contents greater than,

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say, 25%, this method fails for a variety of reasons[2] as follows:

(1) The timber resistivity becomes almost constant and other effects that are of second order at lower moisture contents, for example, temperature, begin to dominate.
(2) Polarization due to electrochemical reactions at the electrodes and higher ionic mobilities become increasingly severe as the timber becomes wetter. This gives rise to problems of short- and long-term drift in the resistance value, with consequent irrepeatibility.
(3) Electrochemically active electrodes cause irreversible deposition of conducting material in the body of the wood, short circuiting the moisture probe and rendering it useless.

An ac technique will solve the problem of polarization provided the frequency is high enough. On the other hand, using an ac technique for measuring moisture content appears at first sight to be unsuitable for the following reasons:

(1) The ac impedance of the wood has been elucidated in detail by several authors.[2-7] The capacitive and resistive parts of the impedance or, equivalently, the wood dielectric constant and loss factor vary in a complex and non-monotonic way as a function of frequency and moisture content.
(2) Impedance is usually measured using ac bridges, balance being achieved manually. Automatic measurement of impedance involves the use of expensive and complex instrumentation.[8]

The Solution

The solution to the problem outlined in this paper comes from the observation that the magnitude of the ac impedance of wood (defined in the usual manner as the magnitude of the ac voltage divided by the magnitude of the ac current) becomes a monotonically decreasing function above about 22%–24% w/w moisture content. Consequently, provided the wood is wetter than this, the moisture content can be estimated by a single measurement of the magnitude of the ac current passing through the probe, for a known driving ac voltage. No phase measurement is necessary.

This paper outlines a compound solution to this problem: at lower mositure contents the dc resistivity technique is used, while at higher moisture contents an ac impedance technique is used. For electronic simplicity two separate but identical probes are used in the actual laboratory situation, one for the dc measurement and the other for the ac measurement, but there is no reason why the same probe cannot be used for both — indeed this was done during the calibration phase of the system development.

Although not strictly necessary, the system is considerably enhanced by controlling which probe is read from a host computer. This allows first an on-line conversion to moisture content, and second, choice of ac or dc measurement according to recent history.

The thrust of this paper is to report a particular solution to this problem. The problem has been solved within the context of BRANZ's work program;[1] in particular: (1) for a certain species of wood, Pinus radiata, and a specific salt preservation treatment, boric treatment to the C8 specification of the New Zealand Timber Preservation Authority;[9] (2) with the requirement of knowing relative moisture contents (i.e., whether a given piece of material became wetter or dryer) being more important than the requirement of knowing absolute moisture contents to high accuracy, particularly for timbers wetter than, say, the fibre saturation point.

Consequently, only a limited calibration program was undertaken with no attempt made to test interspecies variability or the effects of different preservative treatments. Nevertheless, there should be no problems in extending this calibration to other cases according to the user's requirements.

This paper begins by describing the physical nature of the probes used and outlining the associated circuitry used to drive and read them. This includes the issue of data transmission, a particular problem in a datalogging system. Details of the limited calibration program follow, and the paper concludes with a description of the computer software used to read the probes.

PROBE DESCRIPTION

The probes consist of a pair of parallel plates spaced 5-mm apart, each plate being a 10-mm square of 1.2-mm thickness gold-plated brass. The plates are electroplated with gold because it is a metal of low electrochemical activity (brass will take a direct electroplate unlike many other common metals and alloys). Each plate has insulated hook-up wire (7 strands of 0.2-mm diameter wire insulated with PVC) soldered into a small slit sawn into one edge of the plate, the residual solder being filed back flush with the plate. The probes are forced into slits in the wood parallel to the grain, the slits being made using a specially made tool, consisting of two 10-mm wide chisel-type blades 5 mm apart, of the same thickness as the probes. Once the probes are inserted, the slits are sealed with a rubber sealant to ensure liquid moisture cannot enter them.

The AC Measuring Apparatus

The apparatus measures the impedance of the probe by measuring the ac current flowing through it for a known applied 100 kHz ac voltage; see the schematic diagram Figure 1(a). The frequency was chosen as giving the best compromise between polarization risk and electronic simplicity. In practice, however, stray capacitances exist that must be fixed and referred to ground so that they appear in parallel across the oscillator and the ammeter. This is

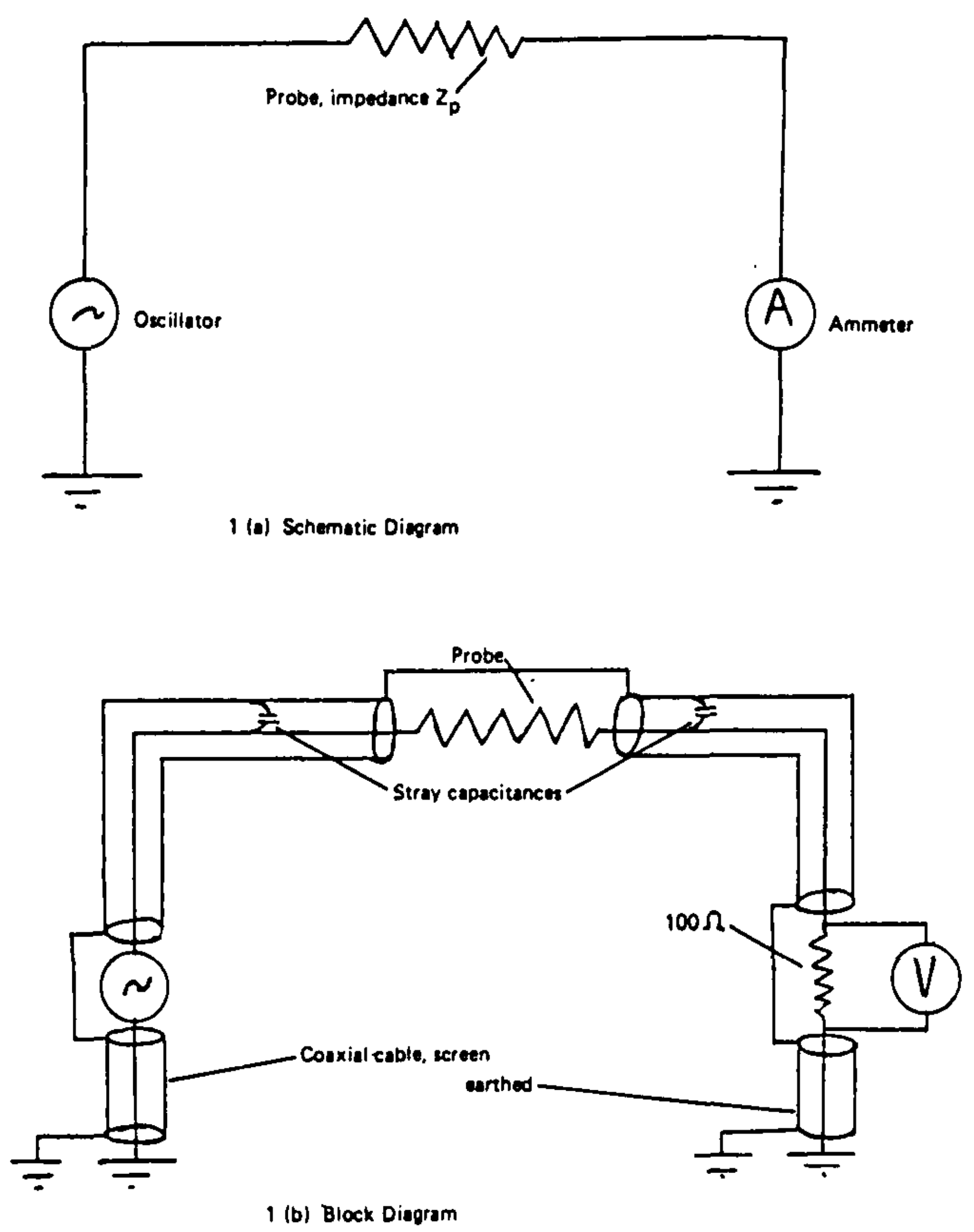

Figure 1. Diagrams of the ac impedance probe measuring circuitry

achieved by using coaxial cable for the main current-carrying circuit leads, with the shield grounded; see Figure 1(b). The ammeter is realized as a resistor across which the voltage is read. The reference resistor must must be small enough to be substantially less than the impedance of the moisture probe, and substantially less than the impedance of the stray capacitances shunted across it. The former is greater than 10^4 ohms and the latter being a few picofarads at 100 kHz is of the order of 10^6 ohms. On the other hand the resistor must be large enough to generate readable voltages. These requirements are met by the choice of a 100-ohm resistor.

The magnitude of the impedance $|Z_p|$ of the moisture probe is now given as:

$$|Z_p| = \frac{|V_p|}{|V_{100}|} \times R_{100} \simeq \frac{|V_{osc}|}{|V_{100}|} \times R_{100}$$

where

$|V_p|$ = voltage amplitude across probe
$|V_{osc}|$ = oscillator voltage amplitude
$|V_{100}|$ = voltage amplitude across resistor
$|R_{100}|$ = reference resistor size

Data Transmission — DC Resistance

The value of the probe resistance is measured at the end of leads some few meters long. As the probe resistance can be very high, up to 1000 Mohms, it is necessary first to use shielded cable to reduce noise, and second, and more importantly, to allow the line and wood capacitance to charge up before taking the final reading. In practice this takes about 30 seconds (indicating a line and wood capacitance of the order of nanofarads).

Data Transmission — AC Impedance

The oscillator output is 10 volts at 100 kHz, giving a minimum voltage across the hundred-ohm resistance of the order of millivolts for a probe impedance of 1 Mohm. To transmit this voltage to the datalogger several meters away, it must be buffered (in order to present the voltage to a high impedance) and amplified (in order to get well above the high frequency noise level of some tens of millivolts). The residual high frequency noise present at the datalogger due to inductive pickup in the cabling is allowed for by subtracting out the reading of another channel with the capacitive probe replaced by an open circuit.

To avoid any remaining problems of polarization drift, the oscillator is automatically switched in to the circuit when the probe is to be read and switched out again when it has been scanned.

CALIBRATION

Calibration Method

A limited calibration was carried out using Pinus radiata, boron treated to C8 specification.[9] As explained, this choice of timber and treatment was dictated by BRANZ's own particular requirement. The probes would need to be recalibrated if other timbers were to be used.

Three samples of this timber were taken from the same stock, each of size 70 × 47 × 90 mm. Their densities were 418 $kg.m^{-3}$, 444 $kg.m^{-3}$, and 520 $kg.m^{-3}$. Probes were placed in the wood and the wood immersed in water for several days. When estimated moisture content was greater than about 50%-60% w/w the samples were withdrawn from the water and placed in polyethylene bags for 24 hours at the working temperature to give the water distribution in the wood time to become more uniform. An ac measurement was taken and the wood then left to dry until the next suitable moisture content had been reached. At this stage the samples were again placed in the plastic bags for 24 hours and another reading taken. The process was repeated until the moisture content dropped to about 30%-35%, when dc resistance measurements were also taken. There is no point in measuring dc resistance for timber wetter than this as the results are unreliable, and worse still there exists the chance of irreversible electrochemical changes in the timber. Once the timber was fully dry (about 10% moisture content), it was re-immersed in water and the whole procedure repeated at another temperature. Temperatures that were used were 5° C and 20° C.

Calibration Results

Figures 2 and 3 show a typical calibration result for one of the probes. The fitted curves can be described by:

AC case

$$\frac{1}{Z - Z_\infty} = Am - B \quad 25 \leq m \leq 50$$

where

Z is the probe ac impedance in ohms
m is the moisture content in % by weight
A, B and Z_∞ are fitting parameters.

DC case

$$\log_{10} R = C + \frac{D}{m^n} \quad 10 \leq m \leq 30$$

where

R is the probe resistance in ohms
C, D and n are fitting parameters.

No attempt has been made to relate these fitting curves to any physical phenomena; they have been chosen merely to parameterize as well as possible the acquired data. Individual probe calibrations show small to moderate scatter about the fitted line (r^2 ranges from 0.86 to 0.99). The combination of this scatter plus the slope of the calibration curve translates into an uncertainty in moisture content for a given impedance or resistance as given in Table 2.

Table 2 gives a measure of the smallest resolvable change in moisture content for an individually calibrated probe. Only if an individual calibration curve is available for each probe can an absolute moisture content be resolved to the precision given in this table. However, even without an individual calibration curve, the table gives the tracking sensitivity of a probe.

In practice it is not practical to calibrate each probe in situ, so one must use a menu calibration curve taken by lumping all the calibration points together. Figures 4 to 7 show the uncertainty bands at about ± one standard deviation that result from this lumping. This gives the likely minimum and maximum moisture content corresponding to a given impedance or resistance reading; the mean of these values is used as a calibration curve. The above formulae are fitted to these mean values and the fitted curve plotted between the uncertainty bands, as appears in Figures 4 to 7. The apparent asymmetry of this curve placement at higher moisture contents is due to this moisture content overaging process. Table 1 contains the values of A, B, C, D and n for these calibration curves.

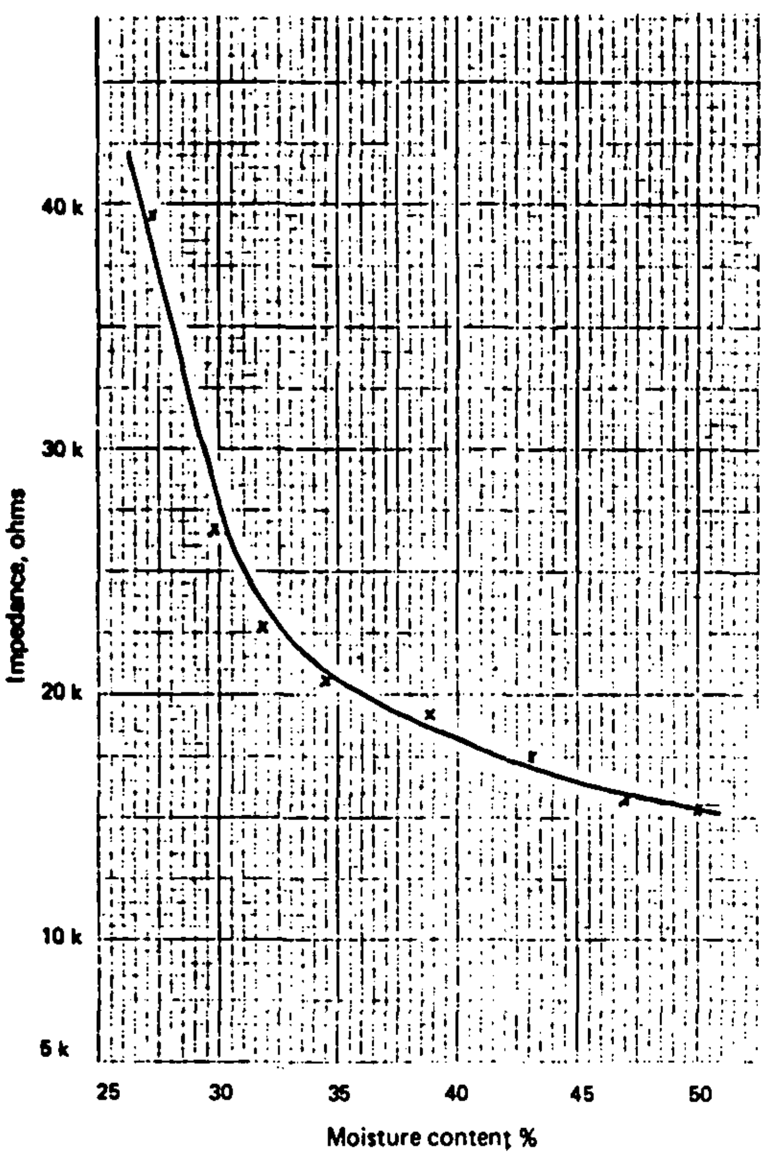

Figure 2. AC impedance at 5° C — typical single probe

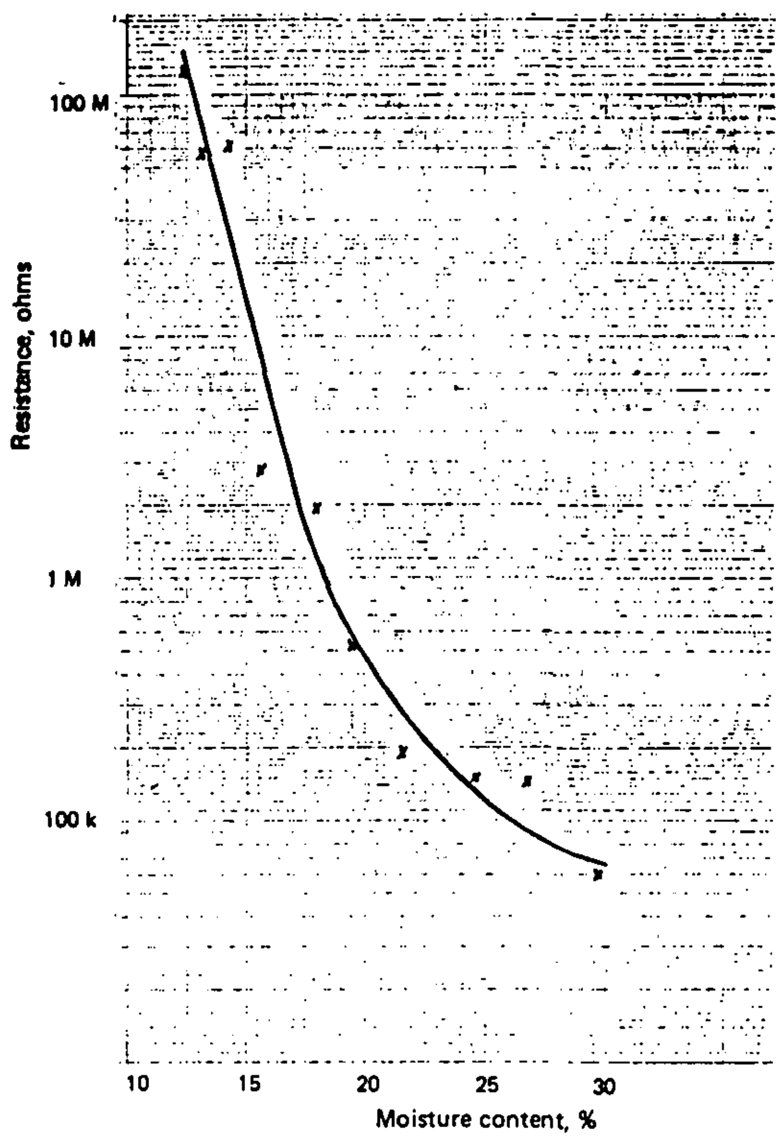

Figure 3. DC resistance at 5° C — typical single probe

Table 1
Fitted Parameters for Moisture Probe Calibration Curves

	AC parameters			DC parameters		
	A	B	$Z\infty$	C	D	n
5° C	1.24×10^{-5}	2.71×10^{-4}	1.20×10^{4}	4.52	8.17×10^{3}	3
20° C	1.28×10^{-5}	2.95×10^{-4}	8.00×10^{3}	1.98	79.3	1

Table 2
Uncertainties in Relative Moisture Content — Within a Single Probe

	Uncertainty in derived moisture content, % by weight			
Moisture content % by weight	AC impedance at 5° C	AC impedance at 20° C	DC resistance at 5° C	DC resistance at 20° C
15	—	—	±0.5%	±0.2%
20	—	—	±1.5%	±1%
25	±0.3%	±0.4%	±4%	±1.5%
30	±1%	±1.5%	±5%	±2%
40	±2%	±4%	—	—

The resulting uncertainties in the moisture content for a given resistance or calibration measurement appear in Table 3. This table gives an estimate in the uncertainty of the absolute moisture content measured if individual probe calibrations are not available.

The most significant and most useful feature in the data collected is the fortuitous overlap in the region of usefulness and accuracy of the two methods: the dc resistance is at its most sensitive and least variable at low moisture contents and becomes consistently less reliable as the moisture content approaches fibre saturation at about 30% by weight moisture content. The ac impedance technique is most accurate between 25%-35% moisture content; indeed, in this range it is better than the dc technique. Below about 22%-24% moisture content, the ac technique is not monotonic, while at higher moisture contents the ac calibration curve becomes flatter so that useful absolute resolution cannot be obtained at more than about 50% w/w moisture content.

For some purposes (e.g., investigations into timber wetting and drying), the tracking ability or relative accuracy (i.e., the minimum detectable moisture change), is of more interest than the absolute accuracy. Where the individual calibration curves are very steep, excellent relative accuracy can be obtained; as Table 2 shows, not until the moisture content exceeds 40% does the relative accuracy fall below ±5% moisture content. Beyond this the ac curve flattens, and once again beyond 50% useful resolution cannot be attained.

The calibration shows that in use the two measuring techniques taken together provide a very good technique for tracking changes in moisture content, often the measurement of most importance, while the absolute accuracy they give remains useful at moisture contents significantly greater than those available from a dc resistance measurement alone.

SOFTWARE

The versatility of the dc/ac moisture probe system can be considerably enhanced if the datalogging equipment itself is controllable by a host computer. This can allow the measured resistance and impedances to be converted online to moisture content, and also allow control over which probe will be measured according to recent history.

The probes and electronics herein described were datalogged using a Hewlett-Packard HP 3497A™ datalogger and HP 3456™ Digital Voltmeter™ controlled via an IEEE-488 bus from a Digital Equipment PDP-11/24™. The software was written with the following considerations in mind:

(1) If the moisture content is below 25%, the ac probe cannot be used.

(2) If the moisture content is above 30% the dc probe cannot be used.

(3) Between 25%-30% moisture content, both techniques are to be used, and a weighted average of the results taken.

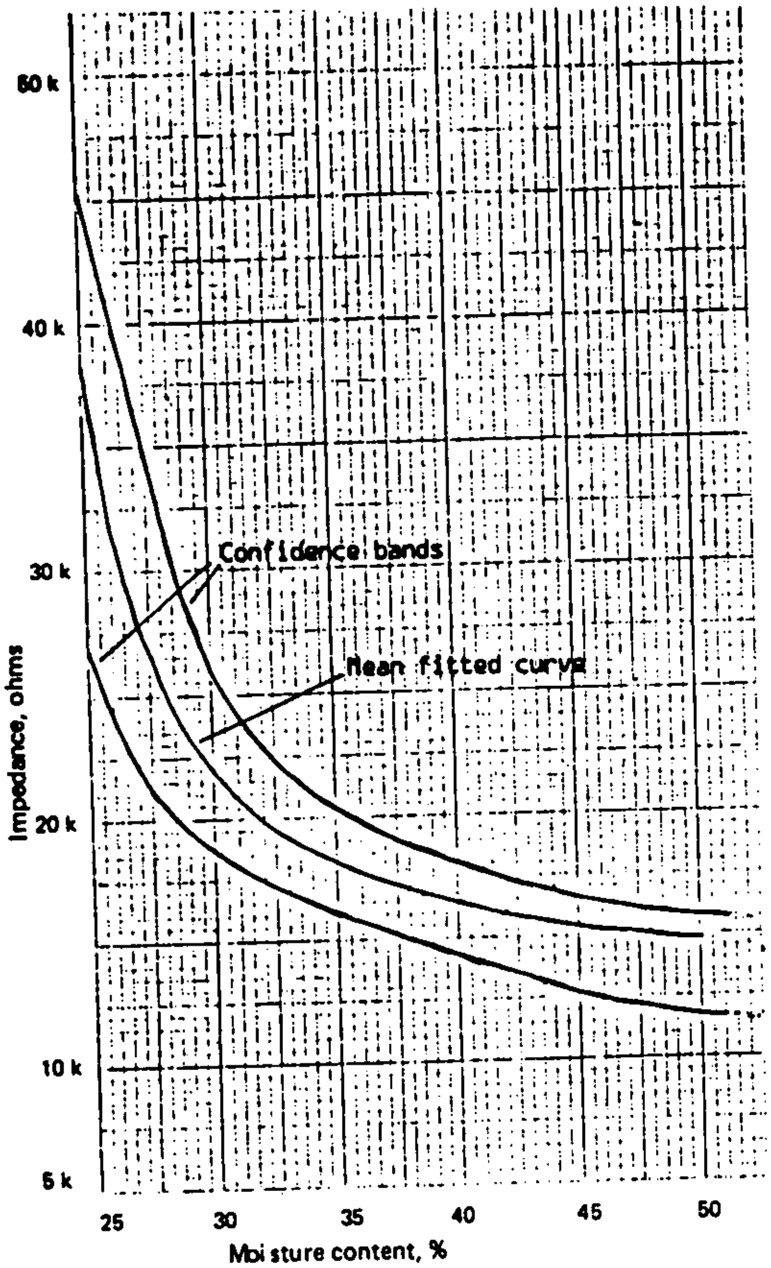

Figure 4. AC impedance at 5° C — all probes

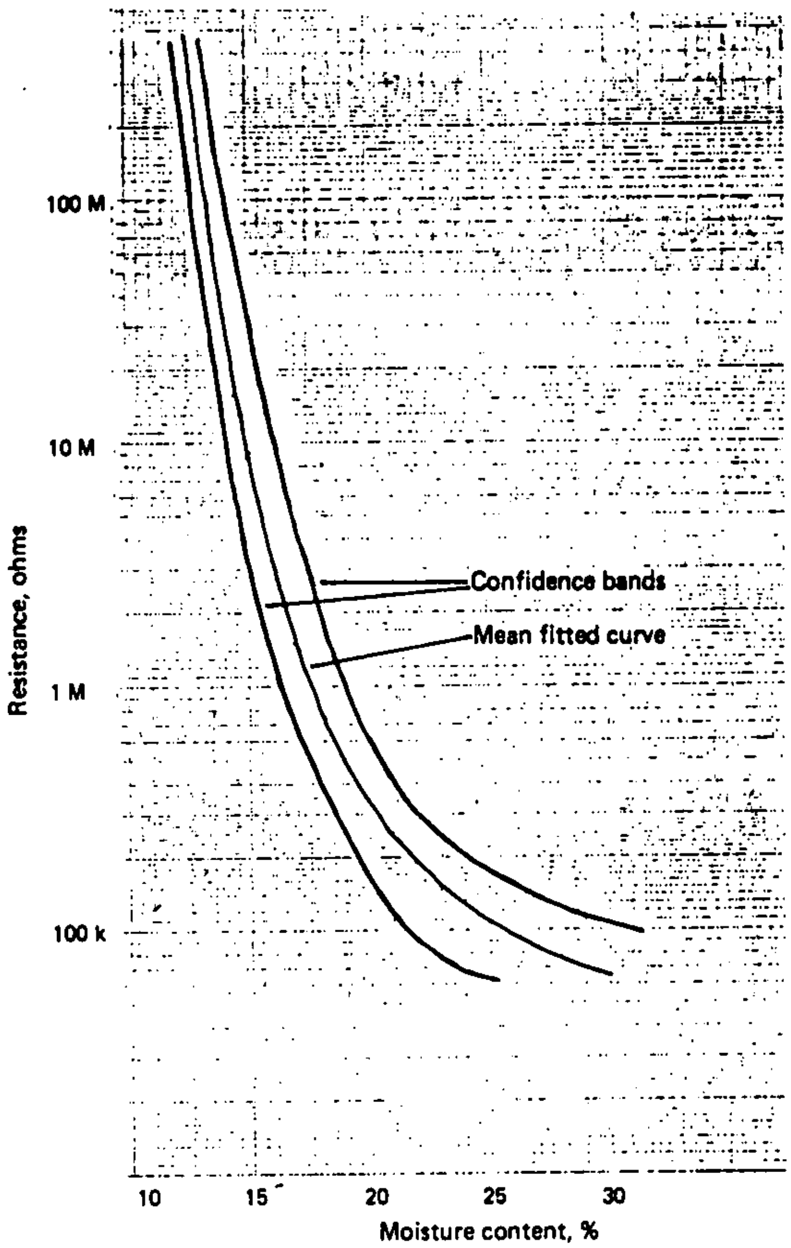

Figure 5. DC resistance at 5° C — all probes

Table 3
Uncertainty in Absolute Moisture Content — All Calibrations Lumped

	Uncertainty in derived moisture content, % by weight			
Moisture content % by weight	AC impedance at 5° C	AC impedance at 20° C	DC resistance at 5° C	DC resistance at 20° C
15	—	—	±1%	±0.5%
20	—	—	±2%	±1.5%
25	±3%	±1%	±5%	±2.5%
30	±3%	±2.5%	±7%	±5.5%
40	±5%	±9%	—	—

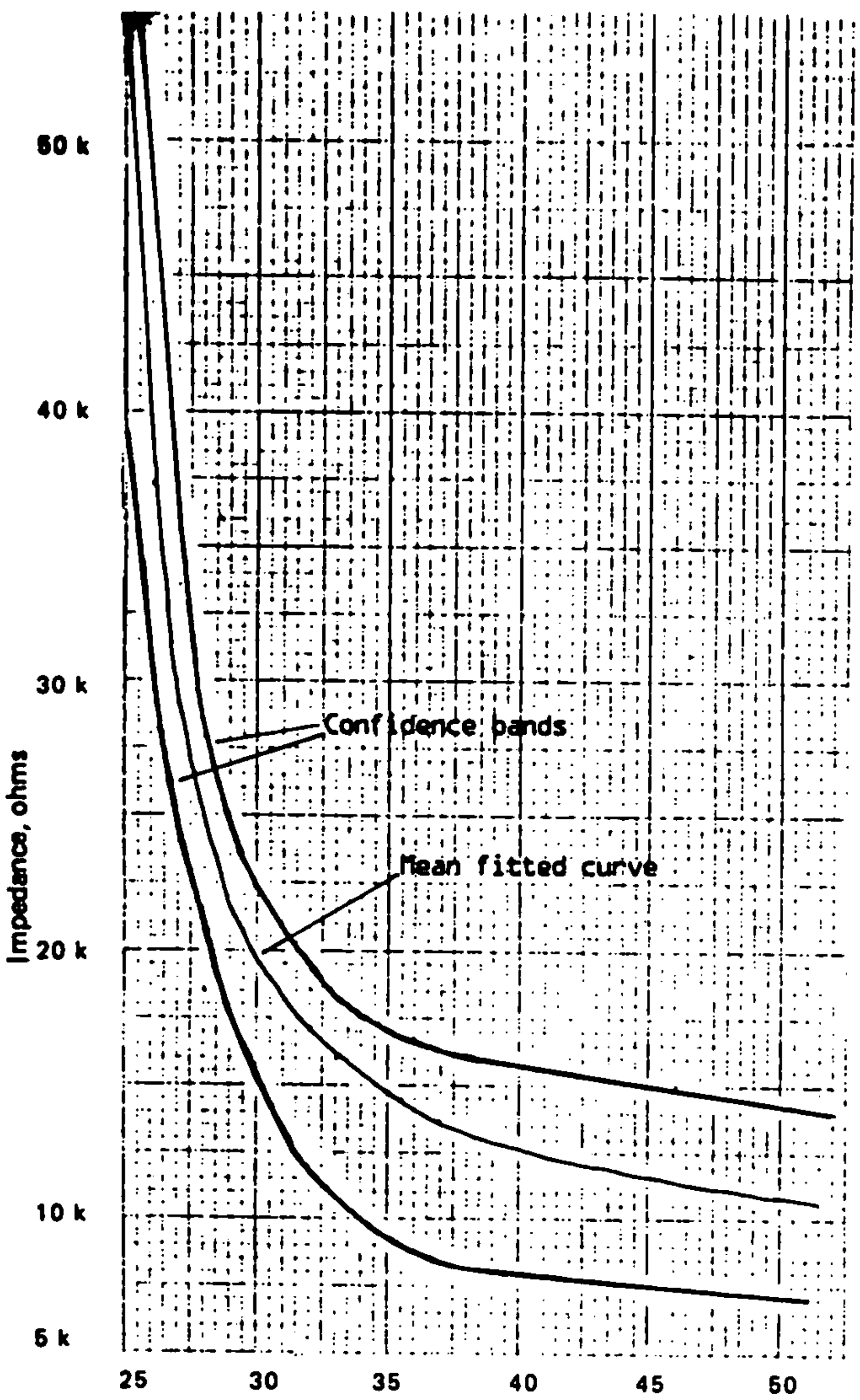

Figure 6. AC impedance at 20° C — all probes

The structure of the software then is:

```
If this is the first reading, then
        Read dc moisture probe
        If dc value ≤ 25%, then
                Moisture content = dc value
        else (dc value > 25%)
                Read ac moisture probe
                Resolve ac and dc values
        end if
else (not the first reading)
If previous reading ≥ 30%,
        Read ac moisture probe
        If ac value ≥ 30%, then
                Moisture content = ac value
        else (ac value < 30%)
                Read dc moisture probe
                Resolve ac and dc values
        end if
else (previous reading < 30%)
```

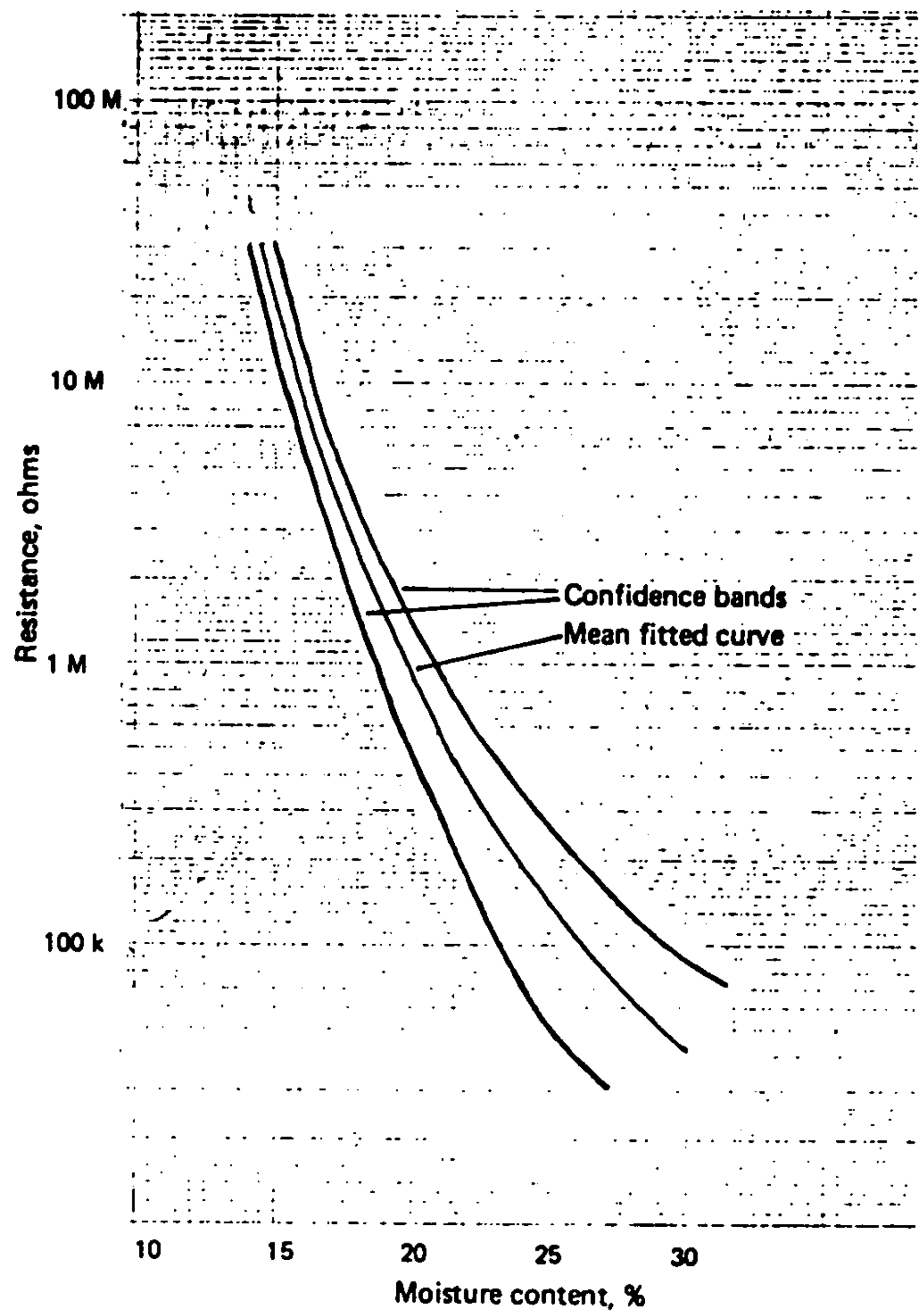

Figure 7. DC resistance at 20° C — all probes

```
                Read dc moisture probe
                If dc value ≤ 25%, then
                        Moisture content = dc reading
                else (dc value > 25%)
                        Read ac moisture probe
                        Resolve ac and dc values
                end if
        end if
end if
Procedure "Resolve ac and dc values"
If ac value ≥ 30%, then
        Moisture content = ac value
else if dc value ≤ 25%,
        Moisture content = dc value
else
        Moisture content = weighted mean of ac and
                                dc values
end if
```

CONCLUSION

This paper offers a solution to the problem of automatically measuring and datalogging timber moisture contents over a very wide range for prolonged periods in a laboratory situation. It does not attempt to offer a universal calibration for the probes as this will be somewhat material — specific; however, other workers should have no difficulty in uplifting the technique presented here and calibrating for their own particular needs.

The solution arrived at is a compound technique. The classical dc resistance technique is used below about 25% moisture content, while above this the magnitude of the ac impedance is measured.

Limited calibration points to the absolute accuracy of the system remaining better than ± 5% moisture content out to about 35% moisture content, while the relative accuracy should be better than ±5% moisture content out to about 40% moisture content. In practice this compound technique has provided a very good method of tracking changes in moisture content, which is often the most useful measurement, even well beyond 50% while retaining a useful absolute moisture content measurement to moisture contents well above fibre saturation. In the overlap region, say 25% to 30% moisture content, the ac technique offers better absolute and relative accuracy than the dc technique. This highlights the sometimes ignored fact that dc resistance moisture measuring devices are quite inaccurate above 25% moisture content.

Some improvements could be made if necessary: a lower moisture content than about 10%-11% could not be found because the resistance of the probes became too large to be measured. If this were to be a problem, larger and/or more closely spaced probes could be used; data transmission for the ac measurement over longer distances might more easily be done by performing a precision rectification of the ac voltage read across the 100-ohm resistor, and then transmitting a dc signal. This gets around a myriad of ac data transmission problems of noise pickup, line impedance, etc. Generally speaking, both the measurements will be easier if they can be done close to the sample and the results transmitted as a dc level to the remote datalogger.

ACKNOWLEDGMENTS

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