ภาคผนวก

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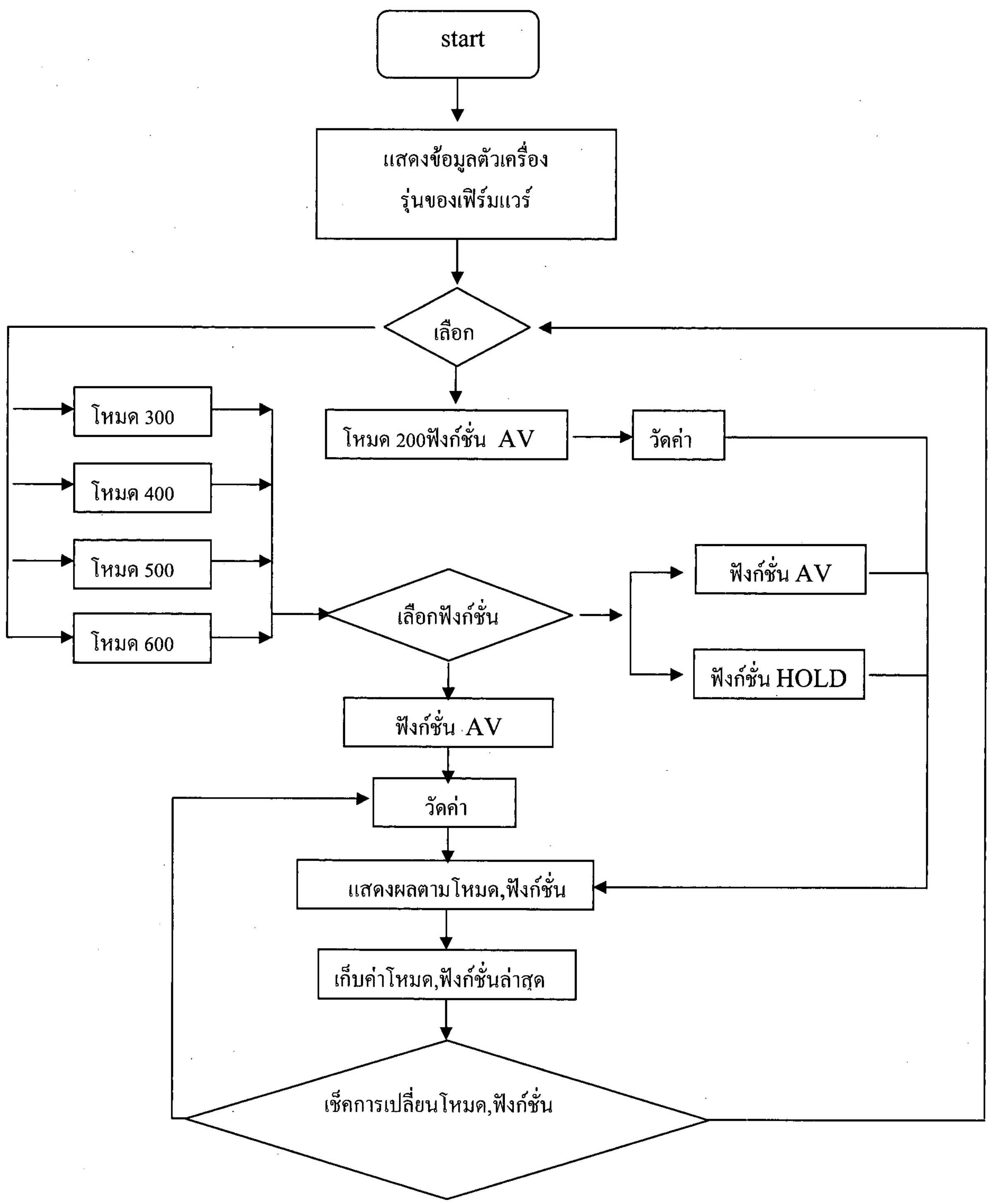
แสดงแผนภาพการทำงานของเครื่องวัดความชื้นไม้



ภาคผนวก ข.

เอกสารงานวิจัยที่เกี่ยวข้อง

Measurement system for long-term recording of wood moisture content with internalconductively glued electrodes

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Abstract

Moisture as an important influence factor on fungal growth needs to be considered for service life prediction of wood and wood-based products. Therefore, a long-term moisture measuring and data logging method for wood in weathered conditions was developed. The method is based on measuring the electrical resistance with glued electrodes for sustainable connection. The measuring point at the tip of the electrodes was glued conductively into the wood, the remaining outer part of the electrodes was glued with an isolating glue. For this purpose, special conductive and isolating glues and electrodes were developed and comparatively evaluated in laboratory tests. The most suitable system consisted of a 2k-epoxy resin, serving for the isolating glue and also as conductive glue (when mixed with graphite powder and ethanol) in combination with a partly isolated stainless steel cable, acting as both, electrode and cable. This system was further tested in combination with mobile mini data logger at 29 different exposure sites in Europe and the United States. After 4–6 years of natural weathering with many extreme climatic and moisture changes, no loosening or other detectable abnormality in 541 pairs of electrodes was observed. The data logging systems were working without any problems for 5 years with the first and only battery, and without any additional maintenance. For the calibration of the measuring system, resistance characteristics were determined for different provenances of Scots pine (Pinus sylvestris L.), Norway spruce (Picea abies Karst.), and Douglas fir (Pseudotsuga menziesii Franco). r 2007 Elsevier Ltd. All rights reserved.

Keywords: Decay factor; In-service performance; Long-term adhesion; Moisture content; Polarisation; Service life prediction

1. Introduction

Service life prediction of wood is required by more and more building codes worldwide [1] and thus methods for the quantification of decay influencing factors are sought. The wood moisture content (MC), the wood temperature, and their dynamics can be expressed as the ''material climate'' of wood [1], which directly determines the service life of wooden components. Moisture has an essential influence on fungal growth and is for this reason an important factor for the prediction of service life of wooden constructions [1,2]. Against this background, it is advisable to measure and record the electrical resistance in the inner part of wood exposed to weather over a long period of time to determine moisture [3,4]. The MC can be measured by metal electrodes

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which are incited in the wood. A problem is the inability of metal to produce a sustainable mechanical adhesion to the wood cells. Consequently, the electrodes do not maintain electrical contact due to the swelling and shrinking of wood [5,6]. Especially in long-term measurements, two types of errors are conceivable [7]:

1 A lower resistance is measured because of the entry of water in the capillary interstices along the electrode.
2 A higher resistance is measured because of the decreasing contact pressure between electrode and wood resulting in its loosening.

The capillary water uptake can be avoided by gluing the upper part of the electrode in the wood [8]. However, this does not prevent the most important measuring point at the tip of the electrode from declining contact. As a consequence, a sustainable and isolating connection

0360-1323/$ -see front matter r 2007 Elsevier Ltd. All rights reserved.
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United States Patent [19]
Parker et al.
[11] **Patent Number: 4,580,233**
[45] **Date of Patent: Apr. 1, 1986**

[54] **METHOD OF MEASURING MOISTURE CONTENT OF DIELECTRIC MATERIALS**

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[73] Assignee: **Weyerhaeuser Company**, Tacoma, Wash.

[21] Appl. No.: **421,624**
[22] Filed: **Sep. 22, 1982**
[51] **Int. Cl.**[4] **G01N 25/56**; G01R 27/26
[52] **U.S. Cl.** .... **364/550**; 73/73; 324/61 R; 364/482
[58] **Field of Search** .... 73/73, 74; 324/61 R, 324/61 P; 364/550, 482

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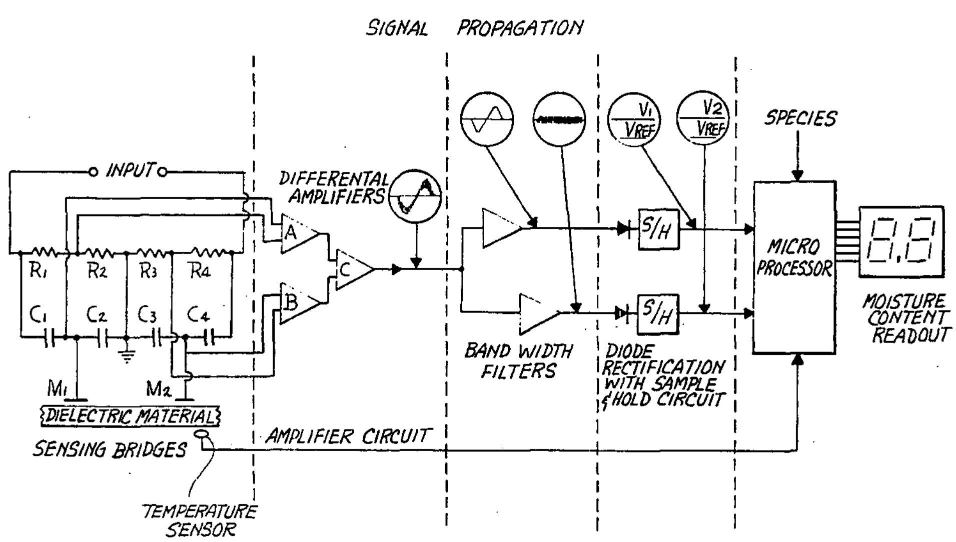
Primary Examiner—Errol A. Krass
Assistant Examiner—Edward R. Cosimano

[57] **ABSTRACT**

The present invention is a method for measurement of moisture in dielectric materials. It is particularly useful for lumber. In the preferred version, at least two alternating current signals whose frequencies differ by a factor of at least 10 are capacitively coupled to the material. The coupling electrodes are in bridge circuits whose unbalance is measured at each frequency. The temperature of the dielectric material is also determined. Bridge unbalance signals are separated and rectified and the voltages, as well as a temperature analog voltage, are entered into a microprocessor programmed with a suitable algorithm to calculate a temperature corrected moisture value. The method overcomes significant inaccuracies in moisture readings due to temperature dependency.

48 Claims, 5 Drawing Figures



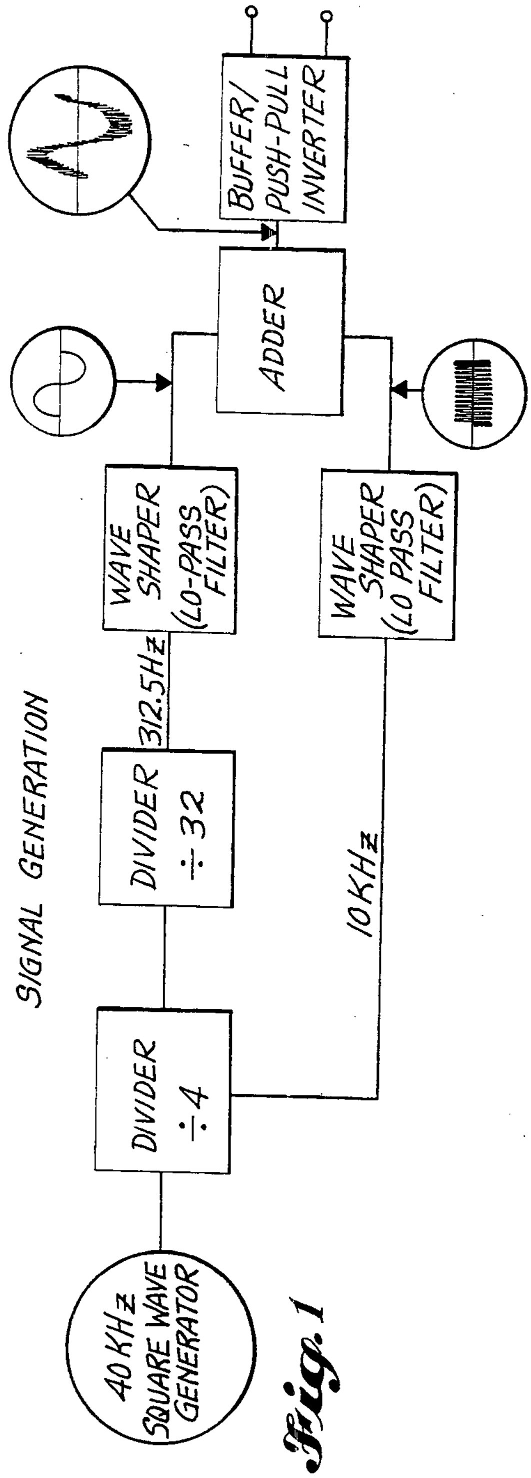

SIGNAL GENERATION
40 KHz SQUARE WAVE GENERATOR
DIVIDER ÷ 4
DIVIDER ÷ 32
312.5Hz
10KHz
WAVE SHAPER (LO-PASS FILTER)
WAVE SHAPER (LO PASS FILTER)
ADDER
BUFFER/ PUSH-PULL INVERTER

Fig. 1

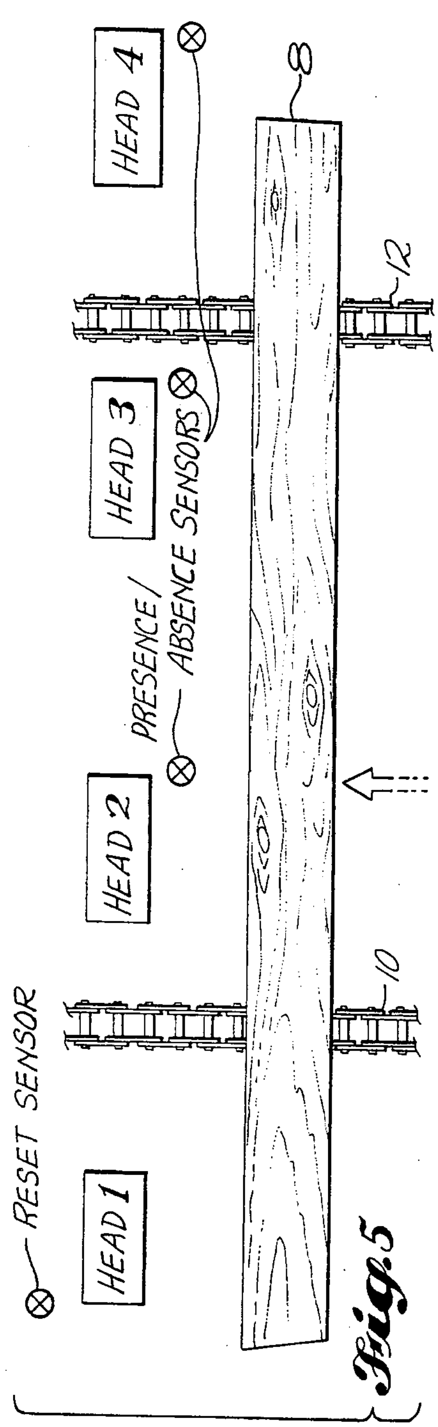

RESET SENSOR
HEAD 1
HEAD 2
HEAD 3
HEAD 4
PRESENCE/ ABSENCE SENSORS
8
10
12

Fig. 5

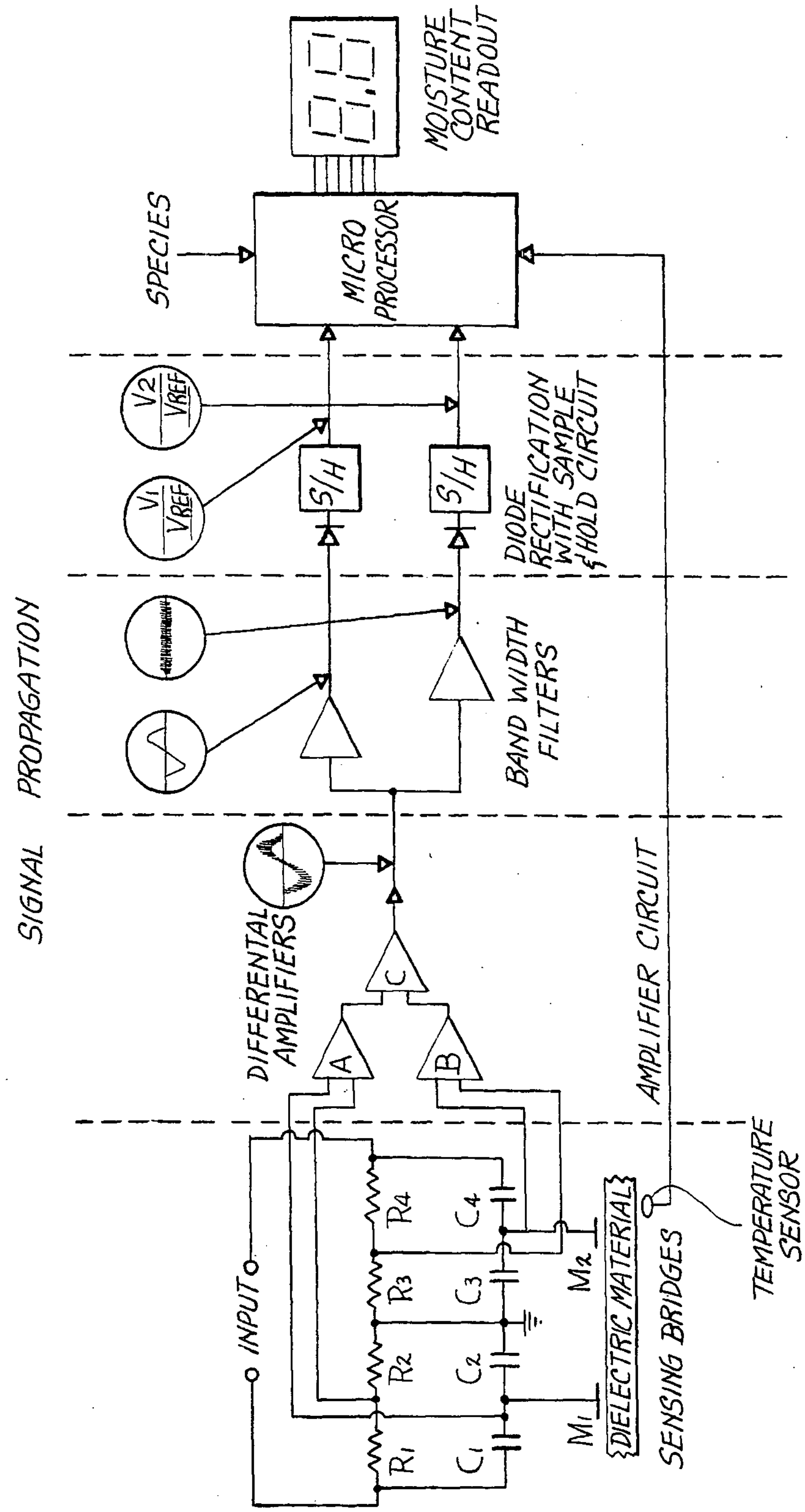
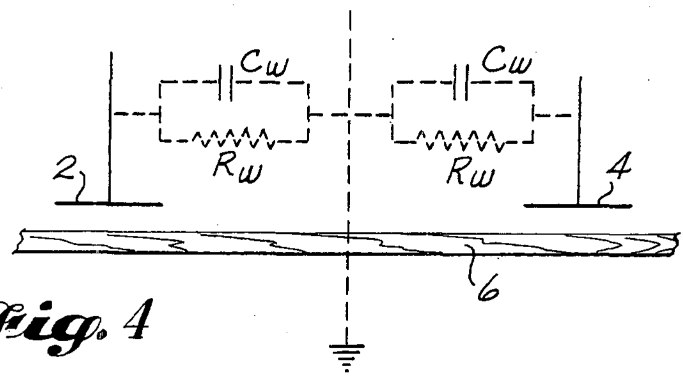
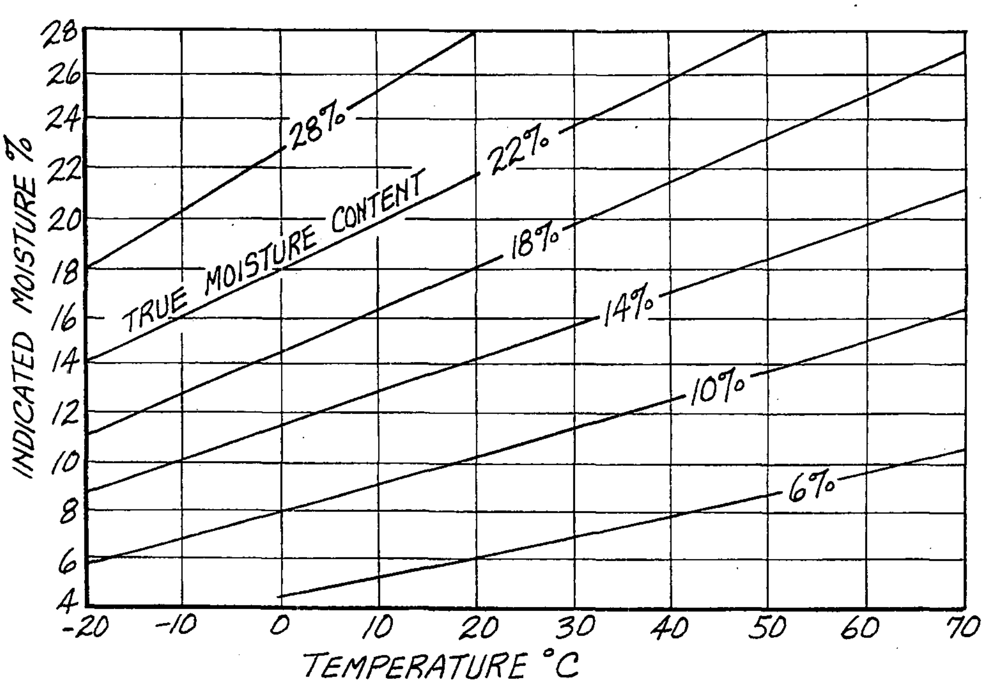

MOISTURE CONTENT READOUT
SPECIES
MICRO PROCESSOR
V2/VREF
V1/VREF
S/H
S/H
DIODE RECTIFICATION WITH SAMPLE & HOLD CIRCUIT
PROPAGATION
BAND WIDTH FILTERS
SIGNAL
DIFFERENTAL AMPLIFIERS
C
A
B
AMPLIFIER CIRCUIT
INPUT
R1
R2
R3
R4
C1
C2
C3
C4
M1
M2
DIELECTRIC MATERIAL
SENSING BRIDGES
TEMPERATURE SENSOR

Fig. 2



Cw
Cw
Rw
Rw
2
4
6

Fig. 4



28%
22%
18%
14%
10%
6%
TRUE MOISTURE CONTENT
INDICATED MOISTURE %
28
26
24
22
20
18
16
14
12
10
8
6
4
-20
-10
0
10
20
30
40
50
60
70
TEMPERATURE °C

Fig. 3

METHOD OF MEASURING MOISTURE CONTENT OF DIELECTRIC MATERIALS

BACKGROUND OF THE INVENTION

The present invention relates to the measurement of moisture in materials which broadly could be considered as dielectric in their propeties. More specifically, it relates to the determination of moisture by measurement of the impedance of the dielectric material at differing alternating frequencies. Provision is made for correcting errors introduced because of temperature variation and variation in the nature of the dielectric material itself. The method is particularly well adapted for measurement of the moisture content of wood.

It is important to control the moisture content of many materials having dielectric properties. Grain can serve as one example. If the moisture content of stored grain is too high, mold growth and ultimate spoilage can result. Wood is another material in which moisture should desirably be controlled within specified limits which depend upon the ultimate application. Wood intended for construction framing should desirably have a moisture content below 20% to minimize fungal attack. Finish lumber, such as that used for trim and moldings, normally is specified with moisture contents at or near those which will be in equilibrium with the ultimate environment. This is typically in the 7-10% range. Wood which is to be adhesively bonded or laminated is normally dried to moisture contents of 12% or below.

Through the years, a number of nondestructive moisturemeasuring methods have been developed. Most of these depend upon some electrical property of the material being measured. The earliest instruments for measuring the moisture content of wood determined its electrical resistivity by passing a direct current through it. Handheld moisture meters were soon developed so that moisture content could be readily estimated in either the manufacturing plant or in the field where the product was being used. These normally comprise a pair of pins or needles of predetermined size and spacing which are driven into the wood along the grain direction. The needles are connected to a direct current source and a megohmeter, which is precalibrated to give a direct estimate of moisture content. Similar meters have been developed for measurement of the moisture in many other materials.

Another type of meter was developed somewhat later that did not depend on making direct contact with the material. These are typically capacitively coupled. They are suitable for use on conveyor lines in a manufacturing plant, and are often used in conjunction with ancillary equipment which can mark or reject high moisture samples for later redrying. Internal impedance is the property most commonly measured. In many cases the internal resistance is by far the most important component of the impedance. Thus, many of the noncontact meters are similar to the direct-current meters in their use of resistivity to estimate of moisture content.

In the case of wood, resistivity is an almost ideal parameter to measure because of its great variation with relatively small differences in moisture content. The resistance of Douglas-fir at 27° C., using needle electrodes 3.1 cm apart and driven into a depth of 0.8 cm, drops from about 22,400 megohms at 7% moisture content to 0.60 megohms at 24% moisture. Accuracy below this moisture range begins to fall off because of the difficulties in measuring very high resistances. Accuracy also is decreased as the fiber saturation point of the species is approached. No satisfactory instrumental method is yet in use for accurate estimation of moisture content of solid wood members above the fiber saturation point.

The noncontact moisture meters vary considerably in their mode of operation. The most common ones for measuring the moisture content of a dielectric material capacitively couple the material into one arm of a bridge circuit. The bridge unbalance is then measured as two alternating frequencies are impressed across the bridge, either simultaneously or sequentially. These alternating current signals are then filtered into the original component frequencies and rectified to produce DC analog signals. The resultant voltages are a function of the ratio of change in voltage drop across the test capacitor which correspond to each frequency, when the material being tested is located between the plates of the capacitor. Most typically, the estimated moisture content is calculated from the analog voltages by dividing the higher frequency component by the lower frequency component with the inclusion of appropriate constants. Exemplary meters of this type are shown in the patents to Davidson U.S. Pat. No. 3,155,899; Walls U.S. Pat. No. 3,155,902; Baird U.S. Pat. No. 3,241,062; and Liu U.S. Pat. No. 3,255,412.

In U.S. Pat. No. 3,155,902, Walls notes a number of deficiencies in capacitively-coupled moisture meters. A number of these relates to the internal stability and calibration of the electronic component. Two others are a result of uncontrolled outside influences. Walls notes that the measurement is not independent in the position of material between the capacitor plates. He further notes that the measured moisture content has a temperature dependency. However, the inventor offers no solutions for either of these problems. Perry, in U.S. Pat. No. 3,339,137 and 3,354,388, shows a noncontact meter that overcomes the position problem by using opposed electrodes having a fieldfree region between them. His electrodes are at equal voltage and polarity. This system provides compensation for positioning and it is essentially immaterial where the dielectric is located in the void space between the electrodes,

Baird, in U.S. Pat. No. 3,241,062, shows a relatively complex system of temperature compensation. This involves a sensor and associated circuitry which uses a servomotor to adjust a series of potentiometers controlling the output voltage of one of the oscillators. A major problem with this system is the lag time associated with electromechanical system.

One problem appears to be as yet unaddressed. A given moisture meter is normally calibrated so as to work only on a specific dielectric material. Even in the measurement of wood moisture content there is uncompensated variation from species to species. Meters are normally calculated on the basis of coastal Douglas-fir. If, for example, a meter so calibrated is used on pine or hemlock, somewhat different moisture readings will be indicated even though the moisture content of all samples is identical.

The present ivention comprises a method for measuring the moisture content of dielectric materials which has an internal electronic compensation for the temperature and nature of the dielectric material being measured. It is of the general type which employes a plurality of alternating current signals of different frequencies impressed across a bridge circuit into which the sample material is capacitively coupled.

SUMMARY OF THE INVENTION

The present invention is a method of measuring the moisture content of a moisture-containing dielectric material. This is accomplished by capacitively coupling the material into at least one bridge circuit and measuring the resulting bridge unbalance at each frequency when an alternating current having at least two superposed frequencies is applied across each bridge circuit. Within the restrictions imposed by the current state of the art in electronic circuitry, any number n of superposed alternating current frequencies may be applied across the bridge, where n is equal to or greater than 2. Normally two frequencies will give excellent results although resolution is improved with higher numbers of frequencies. The bridge unbalance is determined at each frequency and the AC unbalance voltage at each frequency is converted into a direct-current voltage signal. Simultaneously, the temperature of the material is measured. The direct-current voltages and the voltage analog of the temperature are entered into an algorithm of the following form which can then be solved to display a temperature-corrected moisture content

$$MC = A_0(T) + \sum_{i=1}^{n} B_i(T)\,V_i + \sum_{i=1}^{n}\sum_{j=1}^{n} C_{ij}(T)\,V_iV_j$$

where MC is moisture content, $A_O(T)$, $B_i(T)$, and $C_{ij}(T)$ are all polynomial functions of temperature where n is a whole number equal to or greater than 2, and V_i and V_j are the direct current amplitudes of the ith and jth frequency components.

Accuracy is improved when there is a significant separation between each of the frequencies employed. When only two frequencies are used, it is desirable that they be different by at least a factor of 10. With wood as a dielectric material, excellent results are obtained when the lowest frequency is equal to or less than 1 kHz and the higher frequency is equal to or greater than 10 kHz.

The algorithm to determine moisture content may be solved manually, but it is preferred that the data be entered into a computer such as a microprocessor which gives moisture content as an output on any convenient type of display system.

The nature of the dielectric material will affect the indicated moisture content. Regardless of the material used to calibrate the meter initially, it is within the scope of the present invention to provide simple equations which can compensate for the particular dielectric being measured. For example, appropriate algorithms can be programmed into a microprocessor to correct the initially computed temperature corrected moisture on a given dielectric substance to an actual moisture value, even though the meter was originally calibrated on another dielectric material.

A preferred method uses at least one measuring head in which a pair of coupling electrodes are arranged in a side-by-side relationship. Each electrode is in parallel with a capacitor in one leg of a bridge circuit, with a separate bridge circuit being supplied for each electrode. These bridge circuits are provided in a balanced push-pull arrangement. For many types of dielectric material; e.g., lumber, it is desirable to supply a plurality of measurement heads in a parallel arrangement. In this way the material is sampled at a number of locations. Circuitry can be supplied so that each individual head can give a moisture readout, or the readouts from the heads may be averaged. The latter method is the one that will normally be used, although individual readouts can supply an indication of moisture variation within any given sample.

The method of the present invention will often be used when the material being measured is passing by a series of heads arranged above a conveyor line. To again use the example of lumber, the moisture content of each board will be individually measured. Boards in which the moisture content is above or below a preset range can be mechanically rejected from the line or printed with an indicator dye so that they can be manually removed at some remote location.

Where the sensing heads are located over a conveyor line which is transporting individual dielectric objects to be metered it is convenient to have a detection means in advance of the heads which signals that a new sample is entering the metering zone. Where the samples are of variable size, such as is typical of lumber in a sawmill, a material detection means may be present before each metering head in the assembly. In this way, the circuitry can be arranged so that only those heads which will be fully coupled to the material will be activated. Any heads which are not fully coupled can be disabled or deactivated in some manner so that their outputs do not enter into an averaged value.

It is further beneficial to include a second material detection means immediately following the measuring heads to indicate when the material has moved from the zone in which is it effectively coupled to the heads. This means can send a signal to the microprocessor indicating that the sample has moved from the measuring zone, whereupon the microprocessor can be electronically reset to be ready for measuring the next object which enters the metering zone.

It has been found that when a side-by-side electrode arrangement is used in which the electrodes form part of a capacitive leg of balanced individual bridge circuits, the meter is relatively insensitive to variations in distance between the electrodes and material being measured.

It is an object of the present invention to provide a method for measuring the moisture content of moist dielectric materials which has improved accuracy over methods hereto available.

It is another object to provide a method for measuring the moisture content of dielectric materials which compensates automatically for the temperature of the material being measured.

It is a further object to provide a noncontact method of measuring moisture content of materials which is tolerant of variations in the distance between the material and the measuring head.

It is yet another object to provide a method for measuring the moisture content of materials which provides compensation for the dielectric characteristics of the specific material being measured.

It is still another object to provide a method for accurately measuring the moisture content of individual discreet objects passing by a metering station located adjacent to a conveyor line.

These and many other objects will become readily apparent upon reading the detailed description of the invention when taken in conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing the signal generation section of the moisture meter.

FIG. 2 is a block diagram showing the metering bridges and the signal processing section of the meter.

FIG. 3 is a graph showing the variation in apparent moisture content with changes in temperature.

FIG. 4 shows the electrical equivalent of the sample as it is seen by the measuring electrodes.

FIG. 5 is a diagrammatic arrangement showing a piece of lumber passing beneath a plurality of sensing heads.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following detailed description will use wood as an example of a dielectric material whose moisture content is being measured. It will be apparent to one skilled in the art that the method to be described would be suitable for many different types of dielectric materials which tend to absorb moisture. Among these might be grains, starches, sugar, tobacco, fabrics of various types, etc.

Reference to FIG. 1 shows the signal generation section of the moisture meter. The single oscillator employed is a 40-kHz square wave generator. A signal is sent through a first divider which divides the signal produced by a factor of four to produce a 10 kHz output signal. The 10 kHz signal is split and a portion serves as the input to a second divider which divides by a factor of 32 to produce an output having a frequency of 312.5 Hz. Both the 10 kHz and the 312.5 Hz signals are directed to wave-form shapers which remove the harmonic content and deliver an output wave form which is essentially sinusoidal. The wave form shapers are basically low-pass filters designed to pass the selected frequencies. The output of each of the low-pass filters is trimmed to provide a 10-volt peak-to-peak signal. These two signals are then combined in an adder to produce a complex wave which is now 20-volts peak-to-peak. The combined frequencies are finally passed through a buffer/phase inverter which delivers a push-pull output signal to the measuring bridges.

The output from the signal-generating section is delivered to two push-pull bridge circuits. As seen in FIG. 2, the first bridge comprises resistors R_1 and R_2 on one side of the bridge and capitators C_1 and C_2 on the other side of the bridge. The second bridge circuit comprises equivalent resistors R_3 and R_4 on one side and capacitors C_3 and C_4 on the other side. Measuring electrode M_1 is arranged in parallel with capacitor C_2, while measuring electrode M_2 is in parallel with capacitance C_4. The output of the first bridge is entered the first of a matched pair of differential amplifiers, here designated A. The output of the second bridge enters an equivalent differential amplifier B. The output of these differential amplifiers forms the input for a third differential amplifier designated C. The output of amplifier C will still be a complex wave form containing components from the original 10 kHz and 312.5 Hz input signals. The individual components at each frequency will reflect the unbalance in the bridge circuits respectively caused by the 10 kHz and 312.5 Hz input signals.

The output of the final differential amplifier is directed to a pair of filters which separate the individual frequency components from the complex alternating current wave. The results are again individual signals at 10 kHz and 312.5 Hz which are not somewhat diminished over their original amplitude. These are now rectified to produce direct current voltages which can be continuously compared with DC reference voltages reflecting a balanced condition. The DC currents are now directed through sample and hold circuits from which point they enter a microprocessor.

There are normally two other inputs into the microprocessor. One is from a temperature sensor which determines the temperature of the material being measured. This sensor can be a thermistor, infrared detector, or one of the other sensing means well known in the art. Its output is typically a voltage analog. Finally, another input to the microprocessor is an analog voltage signal related to the nature of the dielectric material being measured. In the case of wood, this will normally be the species. The microprocessor is programmed with an algorithm that processes the input information and sends a signal to an output device which indicates the moisture content of the material.

The generalized algorithm has the form

$$MC = A_0(T) + \sum_{i=1}^{n} B_i(T)\, V_i + \sum_{i=1}^{n}\sum_{j=1}^{n} C_{ij}(T)\, V_i V_j$$

where MC is moisture content, $A_0(T)$, $B_i(T)$, and $C_{ij}(T)$ are all polynomial functions of temperature, n is a whole number equal to or greater than 2, and V_i and V_j are the direct current amplitudes of the ith and jth frequency components.

This generalized algorithm covers the situation where n superposed alternating current frequencies are applied across the measuring bridges. In most cases, such as the one just described, n will be equal to 2. When $n=2$, the algorithm may be simplifed to the form

$$MC = a + bV_1 + cV_2 + dV_1V_2$$

where MC is moisture content, V_1 and V_2 are the direct current voltage signals, and the coefficients are temperature dependent according to their relationships

$$a = \sum_{i=0}^{m} a_i T^i;\ b = \sum_{i=0}^{m} b_i T^i;\ c = \sum_{i=0}^{m} c_1 T^i;\ \text{and } d = \sum_{i=0}^{m} d_1 T^i$$

with m being a whole number equal to or greater than 1.

Unless extreme accuracy of measurement is required, for most purposes first-order approximations of the coefficients may be made as follows where $a=a_0+a_1T$, $b=b_0+b_1T$, $c=c_0+c_1T$, and $d=d_0+d_1T$, where T is the temperature of the material being measured.

Coastal Douglas-fir is the reference wood by which most moisture meters are calibrated. For a meter constructed using the previously described circuitry, the algorithm coefficients for Douglas-fir are as follows:

$a_0 =$	1.4	$a_1 =$	0.0326
$b_0 =$	33.7	$b_1 =$	0.346
$c_0 =$	6.13	$c_1 =$	−0.0198
$d_0 =$	−16.1	$d_1 =$	0.141

For any particular meter construction, the coefficients of the algorithm can be determined experimentally by the measurement of dielectric materials having known moisture contents at some predetermined temperature. The temperature may be determined in a number of ways. Where the dielectric has been in a given ambient environment for a sufficient time to attain temperature equilibrium, simply measuring the ambient temperature will be sufficient. Otherwise, conventional measuring instruments can be used to determine the temperature of each sample.

Reference to FIG. 3 shows the error that can be introduced in conventional D.C. resistance moisture readings of wood by failure to account for temperature. This figure is adapted from a chart now widely used in the industry, but it should be considered only an approximation at best. As one example, wood which is to be adhesively bonded to form laminated structural beams generally should have a moisture content of 12% or below. Referring to FIG. 3, wood at 12% true moisture, measured at 20° C., would be acceptable for laminating. If the same wood was measured warm, as at the unstacker following kiln dryers, the indicated moisture kiln content would be considerably higher. When measured at 60° C., the indicated moisture would be about 17.5% even though the actual moisture was 12%. Without a correction being applied, this wood would be unnecessarily rejected as being too wet. To date, it has been so awkward to apply temperature corrections where the sample population literally consists of hundreds of thousands of boards, that it has not been practical to apply an effective form of temperature correction of moisture readings. The forementioned U.S. Pat. No. 3,241,062 to Baird is apparently the only device which attempted to incorporate automatic temperature correction and, for whatever reasons, it has apparently never been commercially produced. The device employing the presently described method appears to be a major step forward in improving the accuracy of moisture determination by automatic, near instantaneous correction of the temperature dependence problem.

The matter of the nature of the dielectric material being measured is another problem which has received very little attention. As mentioned before, moisture meters for wood are normally calibrated on coastal Douglas-fir. The person who wished to use these meters on other species was at some risk of obtaining inaccurate values because of the known differences in dielectric properties between woods of different species. It is readily within the skill of the art to program the microprocessor so that information on the species being measured can be entered simply be setting a switch, or some similar device, to the proper setting. A linear approximation can be used to give a species correction adequate for all practical purposes. This is of the form

$$MC_{corr}=k_1+k_2MC$$

where the coefficients k_1 and k_2 may readily be determined experimentally by measuring wood of different species having known moisture contents. For coastal Douglas-fir, the coefficient k_1 is 0 and k_2 is 1, so that the slope of the curve is unity. For most other commercially important wood species, the coefficient k_1 will fall in the range between 4 and 10 and k_2 will lie between 0.5 and 1.2.

A noncontact capacitively-coupled moisture meter of the type utilized in the present method can normally be used to measure moisture contents from about 4% up to approximately 28%. Somewhat less accuracy will be experienced at the extreme ends of this range. This is true also of resistance-type meters. While the noncontact meter will actually measure the capacitive reactance of the dielectric to which it is coupled, in the above moisture content range the resistance will form the most important component of the reactance. FIG. 4 shows two electrodes 2,4 at opposite instantaneous polarity which are capactively coupled to a piece of wood 6. When these electrodes are wired as shown in FIG. 2 in a push-pull balanced bridge circuit, they will "see" the wood capacitance and resistance as if it was effectively between the electrode and ground. The effective capacitance of C_w is very small so that its reactance is very large at the frequencies employed. This reactance is also large in comparison with R_w. In effect, the meter exemplified herein is actually measuring wood resistance in similar fashion to a D.C. meter having electrodes actually driven into the wood.

FIG. 5 shows a board 8 being borne on conveyor chains 10,12 and approaching a bank of four metering heads. It is assumed that the left ends of all boards approaching the metering station will be in approximately the same position, as could readily be controlled by a line bar, but that these boards will of variable length. Three of the four heads has a sensor immediately preceding it to detect whether or not the board will be fully coupled to the head. These sensors can be electrical switches, photocells, or any other well-known type of proximity indicator. Even the electrical output of the head as a board passes could be programmed into the microprocessor as a presence/absence signal.

In the present example, it is assumed that all of the boards will be long enough to engage at least the first head. It is for this reason that a sensor is not required preceeding it. As shown in FIG. 5, heads 1, 2, and 3 will be activated. Head 4 will not be activated since the board is not long enough to be fully coupled to the head; i.e., the material would not be under the full area of the head. This will indicate to the microprocessor that an average moisture content should be calculated only on the basis of the output of the first three heads. Head 4 will either be deactivated or its output will be ignored in the moisture determination. In addition to giving an average moisture reading, the output may be designed to indicate the moisture content from each head in order to give an indication of the uniformity of moisture distribution within the sample. The microprocessor could also be programmed with ancillary equipment so as to automatically reject a board which showed an overly high moisture content at any measuring head. After the board has passed by the heads, the reset sensor will be triggered to indicate to the microprocessor that the next data received will be from a new sample. Information from each sample passing the measuring heads is stored in the sample and hold circuits (FIG. 2) until it is cleared by the approach of a new sample.

Having thus disclosed the best mode known to the inventors of practicing the present process, it will be apparent to those skilled in the art that many variations can be made without departing from the spirit of the invention. It is therefore intended that the scope of the invention be limited only by the following claims.

What is claimed is:

1. A method of measuring the moisture content of a moisture-containing dielectric material by capacitively coupling it into at least one bridge circuit and measuring the bridge unbalance when an alternating current input having superposed frequencies is applied across each bridge circuit, the improvement which comprises:

a. applying n superposed alternating current frequencies to the bridge, where n is a whole number equal to or greater than 2;

b. determining the bridge unbalance caused at each frequency and converting it into a direct current voltage signal;

c. measuring the temperature of the material; and

d. computing the moisture content by entering the voltage signals and temperature into an algorithm having the form:

$$MC = A_0(T) + \sum_{i=1}^{n} B_i(T)\, V_i + \sum_{i=1}^{n}\sum_{j=1}^{n} C_{ij}(T)\, V_iV_j$$

where MC is moisture content, $A_0(T)$, $B_i(T)$, and $C_{ij}(T)$ are all polynominal functions of temperature n is a whole number equal to or greater than 2, and V_i and V_j are the direct current amplitudes of the ith and jth frequency components.

2. The method of claim **1** which includes providing a computer which receives inputs of bridge unbalance voltage and temperature and solves the algorithm to indicate a moisture content.

3. The method of claims **1** or **2** in which the lowest and highest frequencies differ at least by one power of 10.

4. The method of claim **3** where the lowest frequency is equal to or less than 1 kHz.

5. The method of claim **3** where the highest frequency is equal to or greater than 10 kHz.

6. The method of claims **1** or **2** in which the moisture content is corrected for the particular characteristics of the dielectric material by entering the uncorrected value into the algorithm

$$MC_{corr} = k_1 + k_2MC$$

where k_1 and k_2 are coefficients unique to the dielectric material being measured.

7. The method of claim **6** in which the dielectric material is wood.

8. The method of claims **1** or **2** including providing two bridge circuits in a balanced push pull arrangement each bridge circuit having a sensing electrode in parallel with a capacitor in one leg of the bridge circuit, each electrode having an adjacent zone within which it is effectively capacitively coupled to the material being measured.

9. The method of claim **8** in which the coupling electrodes are arranged side-by-side in a measuring head.

10. The method of claim **9** including providing a plurality of measurement heads arranged in parallel.

11. The method of claim **10** including providing conveying means to convey the dielectric material to and from a working proximity with the measuring heads.

12. The method of claim **11** which includes providing material detection means in advance of the heads to determine which heads which will be fully coupled to the dielectric material and to deactivate any heads which are not fully coupled.

13. The method of claim **11** which further includes providing material detection means following the measuring heads to indicate when the material has moved out of the zone in which it is effectively coupled to the heads.

14. The method of claim **12** which further includes providing material detection means following the measuring heads to indicate when the material has moved out of the zone in which it is effectively coupled to the heads.

15. The method of claim **13** in which the dielectric material is wood.

16. The method of claim **14** in which the dielectric material is wood.

17. In the method of measuring the moisture content of a moisture containing dielectric material by capacitively coupling the material into at least one bridge circuit and measuring the bridge unbalance when an alternating current input having two superposed frequencies is applied across each bridge circuit, the improvement which comprises:

a. determining the bridge unbalance caused at each frequency and converting it into a direct current voltage signal,

b. measuring the temperature of the material, and

c. computing the moisture content by entering the voltage signals and temperature into an algorithm having the form

$$MC = a + bV_1 + cV_2 + dV_1V_2$$

where MC is mositure content, V_1 and V_2 are the direct current voltage signals and the coefficients are temperature dependent according to the relationships

$$a = \sum_{i=0}^{m} a_iT^i,\ b = \sum_{i=0}^{m} b_iT^i,\ c = \sum_{i=0}^{m} c_1T^i, \text{ and } d = \sum_{i=0}^{m} d_1T^i$$

with m being a whole number equal to or greater than 1.

18. The method of claim **17** in which the algorithm coefficients are first order approximations where $a=a_0+a_1T$, $b=b_0+b_1T$, $c=c_0+c_1T$, *and* $d=d_0d_1T$, where T is the temperature of the material being measured.

19. The method of claims **17** or **18** which includes providing a computer which receives inputs of bridge unbalance voltage and temperature and solves the algorithm to indicate a moisture content.

20. The method of claims **17** or **18** in which the lowest and highest frequencies differ at least by one power of 10.

21. The method of claim **20** where the lowest frequency is equal to or less than 1 kHz.

22. The method of claim **20** where the highest frequency is equal to or greater than 10 kHz.

23. The method of claims **17** or **18** in which the moisture content is corrected for the particular characteristics of the dielectric material by entering the uncorrected value into the algorithm

$$MC_{corr} = k_1 + k_2MC$$

where k_1 and k_2 are coefficients unqiue to the dielectric material being measured.

24. The method of claim **23** in which the dielectric material is wood.

25. The method of claims **17** or **18** including providing two bridge circuits in a balanced push pull arrangement each bridge circuit having a sensing electrode in parallel with a capacitor in one leg of the bridge circuit, each electrode having an adjacent zone within which it is effectively capacitively coupled to the material being measured.

26. The method of claim 25 in which the coupling electrodes are arranged side-by-side in a measuring head.

27. The method of claim 26 including providing a plurality of measurement heads arranged in parallel.

28. The method of claim 27 including providing conveying means to convey the dielectric material to and from a working proximity with the measuring heads.

29. The method of claim 28 which includes providing material detection means in advance of the heads to determine which heads will be fully coupled to the dielectric material and to deactivate any heads which are not fully coupled.

30. The method of claim 28 which further includes providing material detection means following the measuring heads to indicate when the material has moved out the zone in which it is effectively coupled to the heads.

31. The method of claim 29 which further includes providing material detection means following the measuring heads to indicate when the material has moved out of the zone in which it is effectively coupled to the heads.

32. The method of claim 30 in which the dielectric material is wood.

33. The method of claim 31 in which the dielectric material is wood.

34. A method of measuring the moisture content of moisture containing dielectric material which comprises:

a. providing at least one pair of electrodes in a coupled relationship with the material;
b. driving the electrodes with an alternating current signal comprising two superposed frequencies so that opposite electrodes of a pair are at essentially equal voltages of opposite polarity, each electrode being located in an arm of separate bridge circuits;
c. sensing the unbalance signals in the bridge circuits caused by the presence of the material adjacent to the electrodes, said signals containing components of unbalance at each frequency;
d. combining the unbalance signals from the two bridges;
e. separating the combined signal into its individual frequency components and rectifying each component to form direct current voltage signals proportional to the bridge unbalance caused at each frequency;
f. sensing the temperature of the dielectric materials; and
g. computing the moisture content by entering the voltage signals and the temperature into an algorithm having the form

$$MC=a+bV_1+cV_2+dV_1V_2$$

where MC is moisture content, V_1 and V_2 are the direct current voltage signals, and the coefficients are temperature-dependent according to the relationships

$$a = \sum_{i=0}^{m} a_iT^i,\ b = \sum_{i=0}^{m} b_iT^i,$$

$$c = \sum_{i=0}^{m} c_iT^i,\ d = \sum_{i=0}^{m} d_iT^i,$$

with m being a whole number equal to or greater than 1.

35. The method of claim 34 in which the algorithm coefficients are first order approximations where $a=a_0+a_1T$, $b=b_0+b_1T$, $c=c_0c_1T$, and $d=d_0+d_1T$, where T is the temperature of the material being measured.

36. The method of claims 34 or 35 which includes providing a computer which receives inputs of bridge unbalance voltage and temperature and solves the algorithm to indicate a moisture content.

37. The method of claims 34 or 35 in which the lowest and highest frequencies differ at least by one power of 10.

38. The method of claim 37 where the lowest frequency is equal to or less than 1 kHz.

39. The method of claim 38 where the highest frequency is equal to or greater than 10 kHz.

40. The method of claims 34 or 35 in which the moisture content is corrected for the particular characteristics of the dielectric material by entering the uncorrected value into the algorithm

$$MC_{corr}=k_1+k_2MC$$

where k_1 and k_2 are coefficients unique to the dielectric material being measured.

41. The method of claim 40 in which the dielectric material is wood.

42. The method of claims 34 or 35 including providing two bridge circuits in a balanced push pull arrangement each bridge circuit having a sensing electrode in parallel with a capacitor in one leg of the bridge circuit, each electrode having an adjacent zone within which it is effectively capacitively coupled to the material being measured.

43. The method of claim 42 in which the coupling electrodes are arranged side-by-side in a measuring head.

44. The method of claim 43 including providing a plurality of measurement heads arranged in parallel.

45. In the method of measuring the moisture content of a moisture containing dielectric material by capacitively coupling the material into at least one bridge circuit and measuring the bridge unbalance when an alternating current input having two superposed frequencies is applied across each bridge circuit the improvement which, comprises:

a. providing a plurality of sensing heads to simultaneously sample the material at a number of different locations, each head having an adjacent sensing zone within which it is effectively coupled to the material being measured,
b. further providing conveyor means for transporting the material into and out of coupled relationship with the heads,
c. using a computer to analyze the bridge unbalance signals at each frequency and indicate moisture content, and
d. determining when the material has moved out of the sensing zone and is no longer effectively coupled to the heads to indicate to the computer that it should reset and await the arrival of a new sample of material.

46. The method of claim 45 which further includes providing a plurality of material detection means in advance of the heads to signal the computer that the material is in position to be fully coupled to any heads which are engaged by the material and to deactivate any heads which are not engaged.

47. The method of claims 45 or 46 which further includes material detection means following the measuring heads to indicate when the material has moved out of the zone in which it is effectively coupled to the heads.

48. The method of claim 47 in which the dielectric material is wood.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,580,233

DATED : April 1, 1986

INVENTOR(S) : Robert S. Parker; Frank C. Beall

It is certified that error appears in the above—identified patent and that said Letters Patent is hereby corrected as shown below:

In column 10, line 37, "$d=d_0d_1T$," should read --$d=d_0+d_1T$, --

Signed and Sealed this

Nineteenth **Day of** *August 1986*

[SEAL]

Attest:

DONALD J. QUIGG

Attesting Officer *Commissioner of Patents and Trademarks*

United States Patent [19]

Wagner et al.

[11] Patent Number: 4,683,418

[45] Date of Patent: Jul. 28, 1987

[54] MOISTURE MEASURING METHOD AND APPARATUS

[75] Inventors: **Edward D. Wagner; Richard R. Trautwein,** both of Rogue River, Oreg.

[73] Assignee: **Wagner Electronic Products, Inc.,** Rogue River, Oreg.

[21] Appl. No.: **638,020**

[22] Filed: **Aug. 6, 1984**

[51] **Int. Cl.**⁴ **G01R 27/26**

[52] **U.S. Cl.** .... **324/61 P;** 324/61 R

[58] **Field of Search** .... 324/61 R, 61 P, 65 R, 324/437

[56] **References Cited**

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3,959,723 5/1976 Wagner .... 324/61 P

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FOREIGN PATENT DOCUMENTS

236230 7/1960 Australia .... 324/61 R

218755 12/1961 Austria .... 324/61 P

2150928 4/1972 Fed. Rep. of Germany .... 324/61 P

Primary Examiner—Reinhard J. Eisenzopf

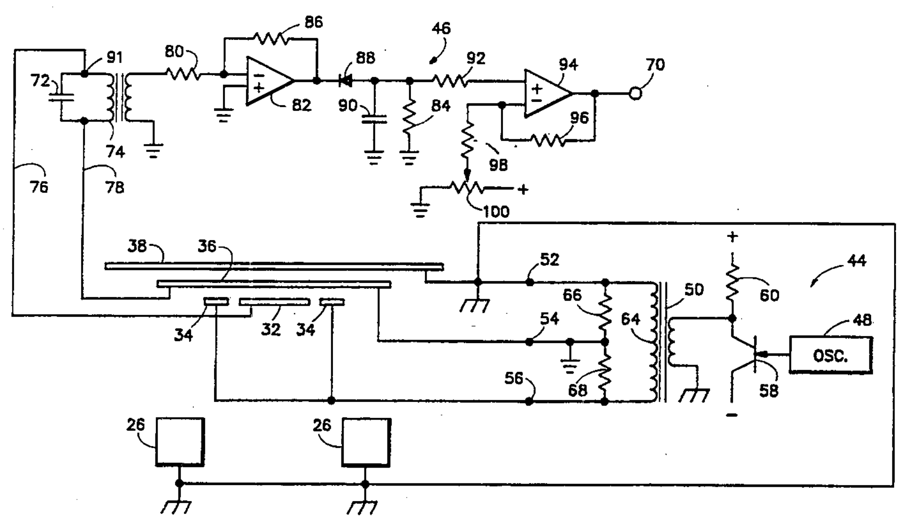
Assistant Examiner—Jose M. Solis

Attorney, Agent, or Firm—Dellett, Smith-Hill and Bedell

[57] **ABSTRACT**

Moisture in wood veneer strips received from a drying oven is measured by passing a first radio frequency signal through the veneer for reception by a receiving plate, transmitting a second radio frequency signal in out-of-phase relation to the first radio frequency signal for reception by the receiving plate, the second signal not passing through the wood. The first and second radio frequency signals induce a potential in the receiving plate, the induction of the first radio frequency signal varying in accordance with the moisture contained in the veneer. The potential of the receiving plate is then measured to determine the extent of moisture in the veneer.

11 Claims, 4 Drawing Figures



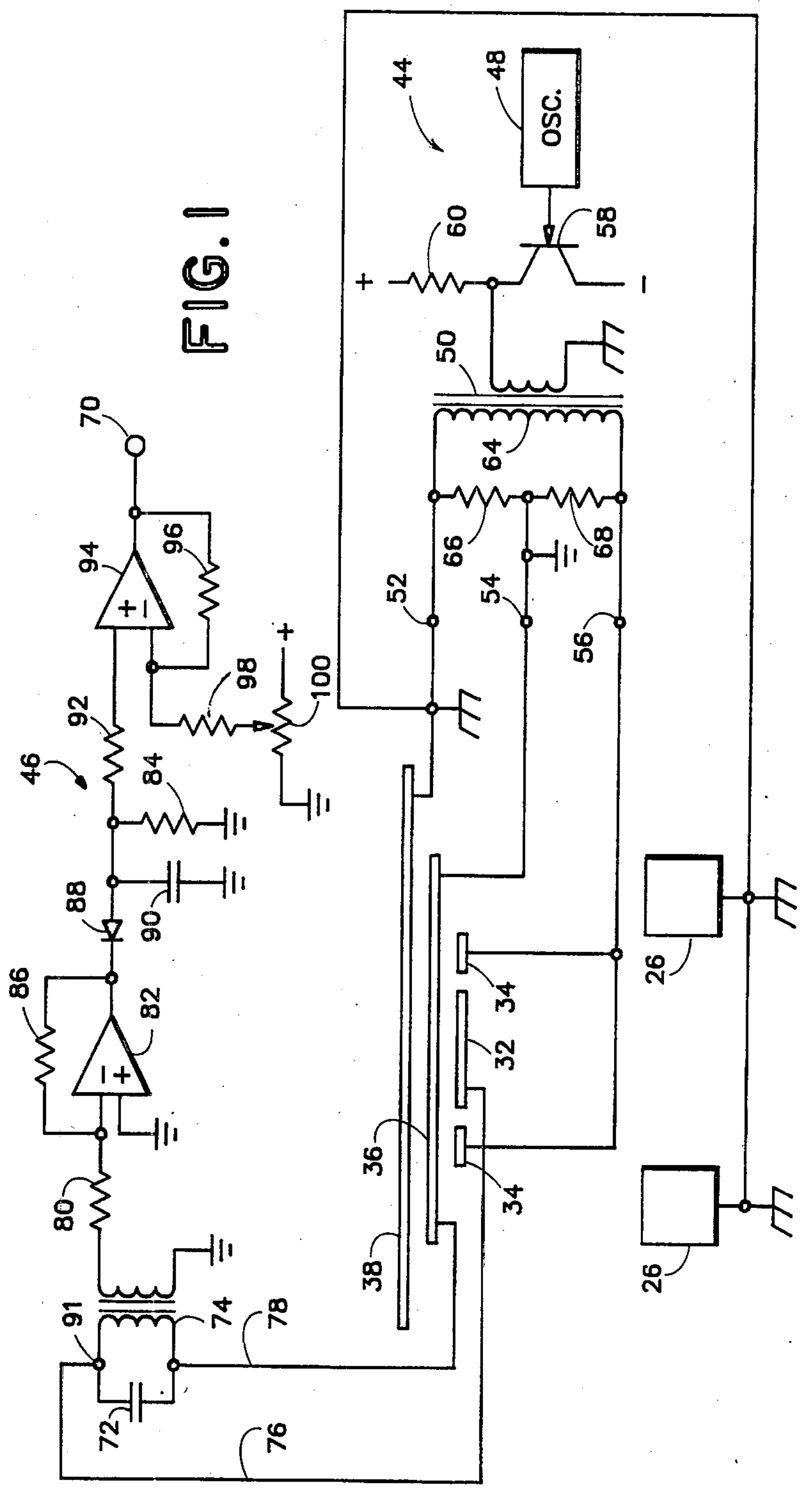

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FIG. 1

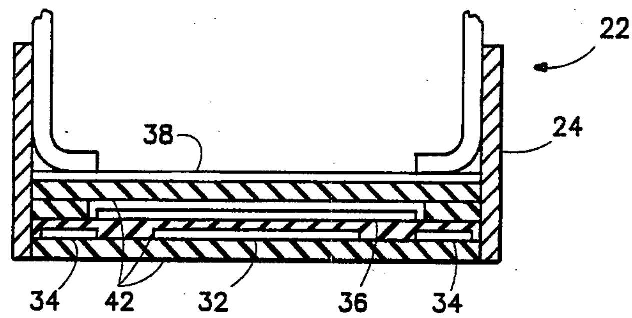
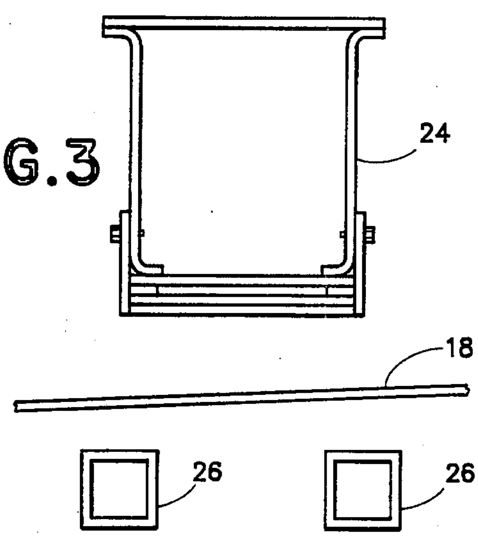


FIG. 2

FIG. 3



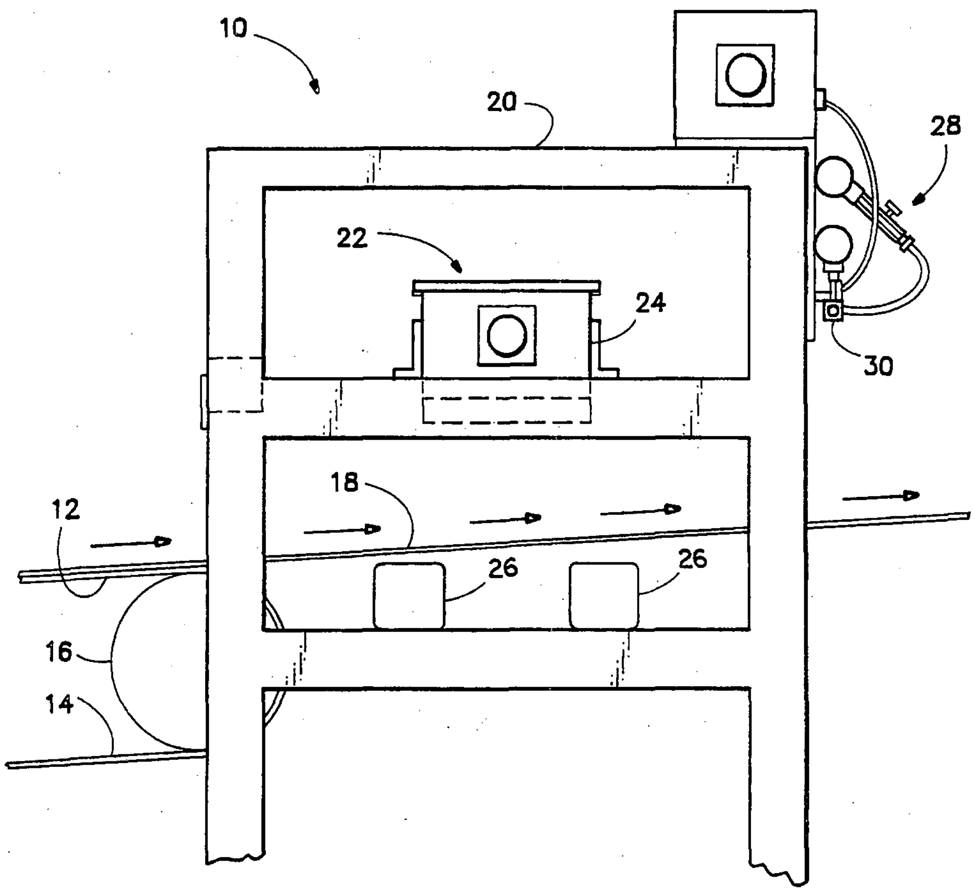


FIG. 4

MOISTURE MEASURING METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to a method and an apparatus for measuring moisture in material, and particularly to an improved apparatus which is less sensitive to the positioning or thickness of the material than prior art devices.

Moisture measuring devices of the prior art typically employ some kind of contacting means for making a conductive connection with material in which moisture is to be measured so that the moisture can be determined by electrical conduction. Unfortunately, the contacting means or brushes are subject to breakage and shorting whereby the moisture indications tend to become inaccurate. Further, even if the brushes are in good condition, the degree of electrical contact provided with the material under test is nonuniform.

Moisture detectors have been developed which do not require contact with the material but instead employ capacitive coupling or the like. Many, however, are quite sensitive to the position of the material relative to the sensor conductor, as well as to the thickness of the material, and therefore indications derived on a production line basis can be somewhat undependable. Also, the conveying means upon which the material is transported can short out the measuring system such that a dependable reading is not obtained.

In prior U.S. Pat. No. 4,377,783, a measuring system is set forth in which transmitting and receiving plates are offset along the path of the measured material, and a conductive path in the veneer and the grounded conveyor is employed as part of the circuit. While very efficacious, there is again some dependency upon accurate contact with the material being measured.

In prior application Ser. No. 494,953 filed May 16, 1983 now U.S. Pat. No. 4,563,635 moisture in wood veneer strips is measured by passing the veneer strips between arrays of plates including a transmitting plate on one side of the veneer and a juxtaposed receiving plate on the other. Phase plates on either side of and on the same level as the transmitting plate are empowered by a signal having the reverse phase to that applied to the transmitting plate. When wet veneer passes between the plate arrays, part of the transmitted signal is shunted reducing the signal received by the receiving plate. While this approach reduces sensitivity to vertical position of the veneer strips, eliminates problems associated with accidental grounding of the veneer and eliminates the need for mechanical contact with the veneer, in practice some unwanted signal shunting occassionally occurs as a veneer sheet initially enters the space between the transmitting and receiving plates, resulting in a false moisture detection signal. Also, the moisture detection apparatus disclosed in the prior application requires use of electronics equipment both above and below the veneer. The equipment mounted below the veneer tends to collect dust and debris which can effect moisture readings.

It would therefore be desirable to provide a moisture detection apparatus wherein moisture detection is not only substantially independent of thickness variations in the veneer and of the vertical position of the veneer between detector and transmitter plates but is also independent of the horizontal position of the veneer as it approaches the transmitting and detecting plates. Further, it would be desirable if the detection apparatus were mountable largely in a single package above the veneer so that dust and debris cannot collect on lower portions of the apparatus and thereby interfere with moisture readings.

SUMMARY OF THE INVENTION

According to the present invention, in a preferred embodiment thereof, the material, e.g. wood veneer, is transported along a path into a region between a sensor assembly and a pair of sensor transmitter bars.

The sensor assembly comprises in part a detector plate, a pair of phase plates on either side of and on the same level as the detector plate, a signal plate parallel with and above the detector and phase signal plates, and a ground plate above and parallel with the signal plate. The sensor assembly also comprises a source of split phase oscillating signal having a neutral, designated "machine ground", coupled to the signal plate, a first oscillating signal output, designated "earth ground", coupled to the ground plate and to the sensor transmitter bars, and a second oscillating signal output, 180 degrees out of phase with the first oscillating signal output and coupled to the phase plates.

When there is no wet veneer between the sensor assembly and the transmitter bars, coupling between the sensor transmitter bars and the detector plate tends to drive the potential of the detector plate toward earth ground. At the same times coupling between the phase plates and the detector plate tends to drive the detector plate to a potential 180 degrees out of phase with earth ground, taking machine ground as a reference. As a result the detector plate, in the absence of a wet veneer, tends to float at a potential relatively near machine ground. When wet veneer enters the area between the sensor assembly and the transmitter bars, coupling increases between the detector plate and the earth grounded transmitter bars, driving the detector plate closer to earth ground. Thus the potential difference between the detector and signal plates is increased in the presence of wet veneer.

The sensor assembly further comprises a detector circuit, mounted above the ground plate, coupled to detect the potential difference between the detector and signal plates and to produce a control signal when the potential difference is high enough to indicate the presence of wet veneer. The control signal may then be used to drive a moisture indicator or alarm.

The ground plate shields equipment mounted above the ground plate from signals transmitted by the signal plate. The signal plate shields and the detector plate from the ground plate so that detector plate potential is primarily dependent on coupling between the detector plate and the phase plates and the transmitter bars. The phase plates help to compensate for changes in vertical position of the veneer; when the veneer moves higher, coupling between the detector plate and the transmitter bars increases driving the detector plate closer to earth ground. However, coupling between the phase plates and the detector plate also increases, driving the detector plate away from earth ground. The two effects tend to cancel for variations in vertical position of th veneer.

The present invention is thus insensitive to vertical position of the veneer and has demonstrated no false readings as veneer is inserted into the sensing area. Further, only the transmitter bars are located below the veneer presenting little opportunity for unacceptable collection of dust or debris. Also the transmitter bars, being at earth ground potential, may be connected to the signal source in the sensor assembly through structural steel only, eliminating the need for extensive wiring to interconnect circuits above and below the veneer.

It is accordingly an object of the present invention to provide an improved apparatus for detecting moisture in plywood veneer or other materials.

It is a further object of the present invention to provide an improved apparatus for moisture detection wherein such apparatus is economical in construction and reliable in operation.

It is another object of the present invention to provide an improved moisture detecting apparatus which is largely independent of vertical positioning of the material relative to the sensing means.

It is a further object of the present invention to provide an improved moisture detecting apparatus which is largely unaffected by collection of dust and debris on components mounted below the material.

It is a further object of the present invention to provide an improved moisture detecting apparatus which does not require extensive electrical connections between circuits above and below the material being tested.

The subject matter which we regard as out invention is particularly pointed out and distinctly claimed in the concluding portion of this specification. The invention, however, both as to organization and method of operation, together with further advantages and objects thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings wherein like reference characters refer to like elements.

DRAWINGS

FIG. **1** is a combination schematic and block diagram of the moisture detecting apparatus according to the present invention.

FIG. **2** is a cross-sectional view of a portion of the sensor assembly showing the relative placement of the phase signal plates, the detector plate, the signal plate and the ground plate according to the present invention.

FIG. **3** is a cross-sectional view of the present invention showing the relative position of the sensor assembly, the sensor transmitter bars, and the material being tested.

FIG. **4** is an end view of the moisture detecting apparatus of the present invention mounted in a frame.

DETAILED DESCRIPTION

Referring to the drawings and particularly to FIG. **4**, illustrating moisture detecting apparatus **10** according to the present invention, a conveyor comprising upper run **12** and lower run **14**, suitably comprising chains or belts, are trained about head roll **16**. The conveyor receives a plurality of plywood veneer strips or pieces **18** from a veneer dryer (not shown), deposited upon the conveyor for transport in the direction indicated by the arrows between the legs of support table 20.

Table **20** carries therebeneath sensor assembly **22**, contained in elongated cabinet **24**, and transmitter bars **26** in parallel relation spaced about **4** inches apart underneath cabinet **24**. The underside of cabinet **24** and the top of transmitter bars **26** are vertically spaced approximately four and one half inches apart in the specific example. Sensor assembly **22** and transmitter bars **26** extend perpendicular to the direction of motion of veneer strips **18** for the width of the conveyor. Table **20** also carries marking means **28** comprising sprayer **30** for marking veneer strips in which a predetermined amount of moisture is detected.

Referring to FIG. **2**, depicting a cross-sectional view of the lower portion of cabinet **24** of sensor assembly **22**, contained in the underside of cabinet **24** are a plurality of longitudinally oriented conducting metal plates supported in generally facing relation to the veneer strips conveyed therebelow. Cabinet **24** centrally supports detector plate **32** and phase signal plates **34** disposed in laterally spaced relation on either side of detector plate **32** and in the plane thereof, i.e. such that a strip of veneer first passes under one of the phase signal plates **34**, then under detector plate **32**, and then under the other phase signal plate **34**. In the specific example, detector plate **32** may have a width of approximately one and a half inches and a length comparable to that of cabinet **24** so as to extend along the width of the entire conveyor system. Phase signal plates **34** in the specific example are each about one half inch wide and are spaced approximately five inches from detector plate **32**. Phase signal plates **34** are also comparable in length to the length of the entire cabinet.

Signal plate **36** is also centrally mounted on the underside of cabinet **24** approximately one sixteenth inch above and in parallel relation with detector plate **32**, the plates being seperated by insulating material **42**. Signal plate **36**, in the specific example, is approximately four and a half inches wide, extending about one and a quarter inch beyond either edge of detector plate **32**. Ground plate **38** is mounted on top of the under side of cabinet **24** about one quarter inch above and in parallel relation with signal plate **36**, separated by insulating material **42**. Ground plate **38** extends over the width of the underside of cabinet **24**, approximately twenty inches in the specific example. Ground plate **38** and signal plate **36** are also comparable in length to the length of cabinet **24**.

The arrays of plates suitably comprise printed or etched conductors on circuit board sections, insulators **42**, composed of epoxy glass and forming the bottom of cabinet **24**.

Referring to FIG. **3**, depicting a cross-sectional view of cabinet **24** and sensor transmitter bars **26** and veneer strip **18**, the top runs **12** of the conveyor are positioned so that the strips **18** of veneer will pass between cabinet **24** and transmitter bars **26** about one half to one inch above the transmitter bars. This spacing is suitable for measuring moisture in wood having a thickness from a fraction of an inch up to about two inches. The strips **18** of veneer may travel at a small angle from horizontal without effecting operation of the present invention.

Referring to FIG. **1**, a combination circuit and block diagram is illustrated for the moisture detector **10** according to the present invention. In addition to plates **32, 34, 36** and **38** mounted on the underside of cabinet **24** sensor assembly **22** further comprises signal generating means **44**. Signal generating means **44** produces radio frequency (suitably 100 KHz) signals at terminals 52 and **56**. With terminal **54** taken as a neutral reference, "machine ground", the signals at terminals **52** and **56** are 180 degrees out of phase with one another. Signal generating means **44** comprises oscillator **48**, suitably comprising a type 12060 integrated circuit manufactured by Motorola, with output to a gate terminal of a VMOS field effect transistor **58**. Transistor **58**, suitably comprising a type VN10KM, has a source terminal connected to a negative supply and a drain terminal connected to a positive supply via resistor **60**. Signal generating means **44** further comprises Ferroxcube cored transformer **50**, with primary driven by the drain voltage of transistor **58**, having secondary winding **64** shunted by resistors **66** and **68** in series. The junction of resistors **66** and **68** forms machine ground terminal **54** while the two leads of the transformer **50** secondary winding provide the earth ground signal at terminal **52** and the reverse phase signal at terminal **56**.

Detector means **46**, connected to detector plate **32** via lead **76** and to signal plate **36** via lead **78**, includes a tuned circuit comprising parallel connected capacitor **72** and the primary winding of ferrite core transformer **74** tuned substantially to the frequency of signal generating means **44**. The signal across the tuned circuit is coupled through transformer **74** and input resistor **80** to a first operational amplifier **82** provided with a feedback resistor **86** and a second input terminal grounded. The AC output of amplifier **82** is detected with diode **88** having its anode coupled to an input of comparator amplifier **94** through resistor **92** and shunted to ground through capacitor **90** in parallel with resistor **84**. Amplifier **94** is provided with a second input terminal coupled via resistor **98** to the moveable tap of potentiometer **100** connected between a positive voltage and ground. The potential between detector plate **32** and signal plate **36** is amplified by amplifier **82** and detected by diode **88** to provide a negative voltage across capacitor **90**. A second input of comparator amplifier **94** is set by means of potentiometer **100** to establish a threshold such that if the negative charge on capacitor **90** increases above a predetermined level, the output at terminal **70** will, via intermediate amplifiers not shown, operate sprayer **30**. That is, moisture is ordinarily indicated when the negative voltage on capacitor **90** is relatively high. Feedback resistor **96** produces a hysteresis effect such that once the sprayer starts to operate, it will continue to do so until the negative voltage across capacitor **90** decreases to a negative value less than the value at which spraying started, whereby eratic or intermittent operation of sprayer **30** is prevented.

Signal plate **36** is coupled to terminal **54** and is thus held at machine ground. Ground plate **38** and sensor transmitter bars **26** are coupled to earth ground at terminal **52**. Phase signal plates **34** are coupled to terminal **56** such that the potential on phase signal plates **34** is 180 degrees out of phase with earth ground.

Considering the overall operation of the moisture detecting apparatus **10** illustrated in FIGS. **1** through **4**, when there is no wet veneer **18** between sensor assembly **22** and transmitter bars **26**, coupling between sensor transmitter bars, at earth ground, and detector plate **32** tends to drive detector plate **32** toward earth ground. At the same time coupling between phase plates **34** and detector plate **32** tends to drive the detector plate to a potential 180 degrees out of phase with earth ground. As a result detector plate **32** in the absence of wet veneer **18**, tends to float at a potential relatively near machine ground. Therefore the potential difference between detector plate **32** and signal plate **36** is relatively small in the absence of wet veneer.

When wet veneer **18** enters the area between sensor assembly **22** and transmitter bars **26**, coupling between transmitter bars **26**, at earth ground, and detector plate **32** increases, driving the detector plate closer to earth ground. Thus the potential difference between detector plate **32** and signal plate **36**, at machine ground, is relatively larger in the presence of wet veneer **18**, and generally increases with the dampness of the veneer.

The increase in potential difference between detector plate **32** and signal plate **36** caused by insertion of wet veneer **18** between sensor assembly **22** and sensor transmitter bars **26** results in an increase in negative charge across capacitor **90** in detector means **46**. If the negative voltage across capacitor **90** is larger than the positive voltage applied to the inverting input of comparator amplifier **94**, comparator amplifier **94** initiates a control signal at terminal **70** causing sprayer **30** to mark the wet veneer. Potentiometer **100** is set such that a control signal output at terminal **70** does not occur unless the negative voltage across capacitor **90** is sufficiently large. Since the voltage across capacitor **90** increases negatively with the dampness of veneer **18**, sprayer **30** does not operate unless veneer **18** is sufficiently damp. Thus the minimum dampness necessary to initiate spraying may be controlled by adjustment of potentiometer **100**.

As the thickness of veneer **18** increases, or as the height of the veneer above the sensor transmitter bars increases, coupling between the veneer and the detector plate increases, tending to drive the potential of detector plate **32** closer to earth ground. However, at the same time, coupling between phase signal plates **34** and detector plate **32** also increases tending to drive the potential of detector plate **32** 180 degrees out of phase from earth ground. Thus the change in signal coupling from phase plates **34** tends to offset the change in the signal coupling from the veneer due to variations in the thickness or vertical position of the veneer, reducing the possibility of a false indication of wetness.

Since the signal detected by sensor assembly **22** is not dependent on signal shunting by veneer **18** partial insertion of veneer **18** in the sensing area beneath sensor assembly **22** does not result in false moisture readings. Also, since dry veneer is of low conductivity, and since detection of moisture depends on the coupling of a large portion of the veneer in the sensor area to earth ground, inadvertent or intentional grounding of the veneer outside the sensing area has no significant affect on moisture sensitivity.

As can be seen, most of the sensing apparatus is contained within cabinet **24** mounted above the veneer. Only the two sensor transmitter bars **26** are mounted below the veneer. Since these bars are connected to earth ground, they may be coupled to equipment in cabinet **24** through the structural steel of table **20**. Therefore no wiring is required between sensing equipment mounted above and below the veneer. Also sensor transmitter bars **26** have small upper surface areas which do not collect much dust or debris and are relatively simple to clean in any case.

While the detection of moisture in veneer is particularly set forth herein, it will be understood that the apparatus is not restricted thereto but is applicable to other materials.

While we have shown and described a preferred embodiment of our invention, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from our invention in its broader aspects. We therefore intend the appended claims to cover all such changes and modifications as fall within the true spirit and scope of our invention.

We claim:

1. Apparatus for measuring the moisture content of material, said apparatus comprising:

first conductor means disposed in spaced facing relation to said material;

second conductor means disposed in spaced facing relation to said material and in adjacent spaced relation to said first conductor means;

third conductor means disposed in facing relation to said material and positioned opposite said first and second conductor means while being generally separated from said first and second conductor means by said material during the presence of said material;

receiving means;

means for energizing said first and third conductor means in out of phase relation with respect to a common reference whereby coupling between first and second conductor means and coupling between second and third conductor means create a potential in said second conductor means during the presence or absence of said material; and

means for connecting said second conductor means to said receiving means for registering said potential of said second conductor means with respect to a fixed reference potential whereby moisture in said material is disposed in coupling relation between said second and third conductor means to alter the potential of said second conductor means so that moisture can be detected according to the change in potential of said second conductor means.

2. The method of measuring the moisture content of material comprising:

passing a first radio frequency signal through said material for reception by a receiving plate;

transmitting a second radio frequency signal in out-of-phase relation to said first radio frequency signal with respect to a common reference, said second signal being transmitted from a source adjacent said receiving plate without passing through said material, said first and second radio frequency signals inducing a potential in said receiving plate, the induction of said first radio frequency signal varying in accordance with the moisture contained in said material; and

measuring the potential of said receiving plate to determine the extent of said moisture.

3. The apparatus according to claim 1 wherein said third conductor means comprises at least one grounded conductive bar positioned beneath the path of said material, said first and second conductor means being located above the path of said material such that said material passes between said third conductor means and the other conductor means.

4. Apparatus for measuring the moisture content of material being conveyed on a conveyor along a generally horizontal path, said apparatus comprising:

a detector conductor adjacent the path of said material on a first side of said conveyor so as to face a first side of said material conveyed on said conveyor;

a first transmitting conductor positioned generally opposite said detector conductor in sufficiently close proximity to said detector conductor so that radio frequency energy can be coupled between said first transmitting conductor and said detector conductor, said first transmitting conductor being adjacent the path of said material on a second side of said conveyor so as to face a second side of material as conveyed on said conveyor;

an additional transmitting conductor positioned adjacent said detector conductor on said first side of said conveyor in sufficiently close proximity to said detector conductor so that radio frequency energy can also be coupled between said additional transmitting conductor and said detector conductor;

receiving means;

means for providing a source of radio frequency energy connected between said first transmitting conductor and said additional transmitting conductor for energizing said first and additional conductors in opposite phase relation with respect to one another whereby coupling between said transmitting conductors and said detector conductor creates a potential in said detector conductor; and

means for connecting said detector conductor to said receiving means for registering said potential of said detector conductor whereby when moisture in said material is disposed in coupling relation between said first transmitting conductor and said detector conductor, the potential of said detector conductor is altered so that moisture can be detected according to the change in potential of said detector conductor.

5. The apparatus according to claim 4 wherein said first transmitting conductor comprises at least one grounded bar positioned beneath the path of said material.

6. The apparatus according to claim 4 wherein said first transmitting conductor comprises a pair of grounded bars positioned beneath the path of said material, and wherein said additional transmitting conductor comprises a pair of plates positioned above the path of said material.

7. The apparatus according to claim 6 wherein said detector conductor is positioned between said pair of plates.

8. Apparatus for measuring the moisture content of material being conveyed on a conveyor along a generally horizontal path, said apparatus comprising:

a detector conductor adjacent the path of said material on a first side of said conveyor so as to face a first side of said material conveyed on said conveyor;

a first transmitting conductor positioned generally opposite said detector conductor in sufficiently close proximity to said detector conductor so that radio frequency energy can be coupled between said first transmitting conductor and said detector conductor, said first transmitting conductor being adjacent the path of said material on a second side of said conveyor so as to face a second side of material as conveyed on said conveyor;

an additional transmitting conductor positioned adjacent said detector conductor on said first side of said conveyor in sufficiently close proximity to said detector conductor so that radio frequency energy can also be coupled between said additional transmitting conductor and said detector conductor;

receiving means;

means for providing a source of radio frequency energy connected between said first transmitting conductor and said additional transmitting conductor whereby coupling between said transmitting conductors and said detector conductor creates a potential in said detector conductor;

wherein said means for providing a source of radio frequency energy includes first and second output terminals coupled respectively to said first and additional transmitting conductors;

means for connecting said detector conductor to said receiving means for registering said potential of said detector conductor whereby when moisture in said material is disposed in coupling relation between said first transmitting conductor and said detector conductor, the potential of said detector conductor is altered so that moisture can be detected according to the change in potential of said detector conductor;

wherein said means for connecting said detector conductor to said receiving means includes a return path at a reference level intermediate said first and second terminals of said source of high frequency energy;

a signal plate connected to said return path and positioned on the remote side of said detector conductor from said first transmitting conductor; and

a grounding plate located on the remote side of said signal plate from said first transmitting conductor.

9. The apparatus according to claim **4** wherein said means for providing a source of radio frequency energy includes first and second output terminals coupled respectively to said first and additional transmitting conductors, and wherein said means for connecting said detector conductor to said receiving means includes a return path at a reference level intermediate said first and second terminals of said source of high frequency energy.

10. The apparatus according to claim **9** further including a signal plate connected to said return path and positioned on the remote side of said detector conductor from said first transmitting conductor.

11. Apparatus for measuring the moisture content of material being conveyed on a conveyor along a generally horizontal path, said apparatus comprising:

a detector conductor adjacent the path of said material on a first side of said conveyor so as to face a first side of said material conveyed on said conveyor;

a first transmitting conductor positioned generally opposite said detector conductor in sufficiently close proximity to said detector conductor so that radio frequency energy can be coupled between said first transmitting conductor and said detector conductor, said first transmitting conductor being adjacent the path of said material on a second side of said conveyor so as to face a second side of material as conveyed on said conveyor, wherein said first transmitting conductor comprises a pair of grounded bars positioned beneath the path of said material;

an additional transmitting conductor positioned adjacent said detector conductor on said first side of said conveyor in sufficiently close proximity to said detector conductor so that radio frequency energy can be coupled between said additional transmitting conductor and said detector conductor, wherein said additional transmitting conductor comprises a pair of plates positioned above the path of said material and wherein said detector conductor is positioned between said pair of plates;

receiving means;

means for providing a source of radio frequency energy connected between said first transmitting conductor and said additional transmitting conductor whereby coupling between said transmitting conductors and said detector conductor creates a potential in said detector conductor;

means for connecting said detector conductor to said receiving means for registering said potential of said detector conductor whereby when moisture in said material is disposed in coupling relation between said first transmitting conductor and said detector conductor, the potential of said detector conductor is altered so that moisture can be detected according to the change in potential of said detector conductor; and

further including a grounding plate located above said detector conductor on the remote side of said detector conductor from said first transmitting conductor.

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