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# Electric Moisture Meters for Wood

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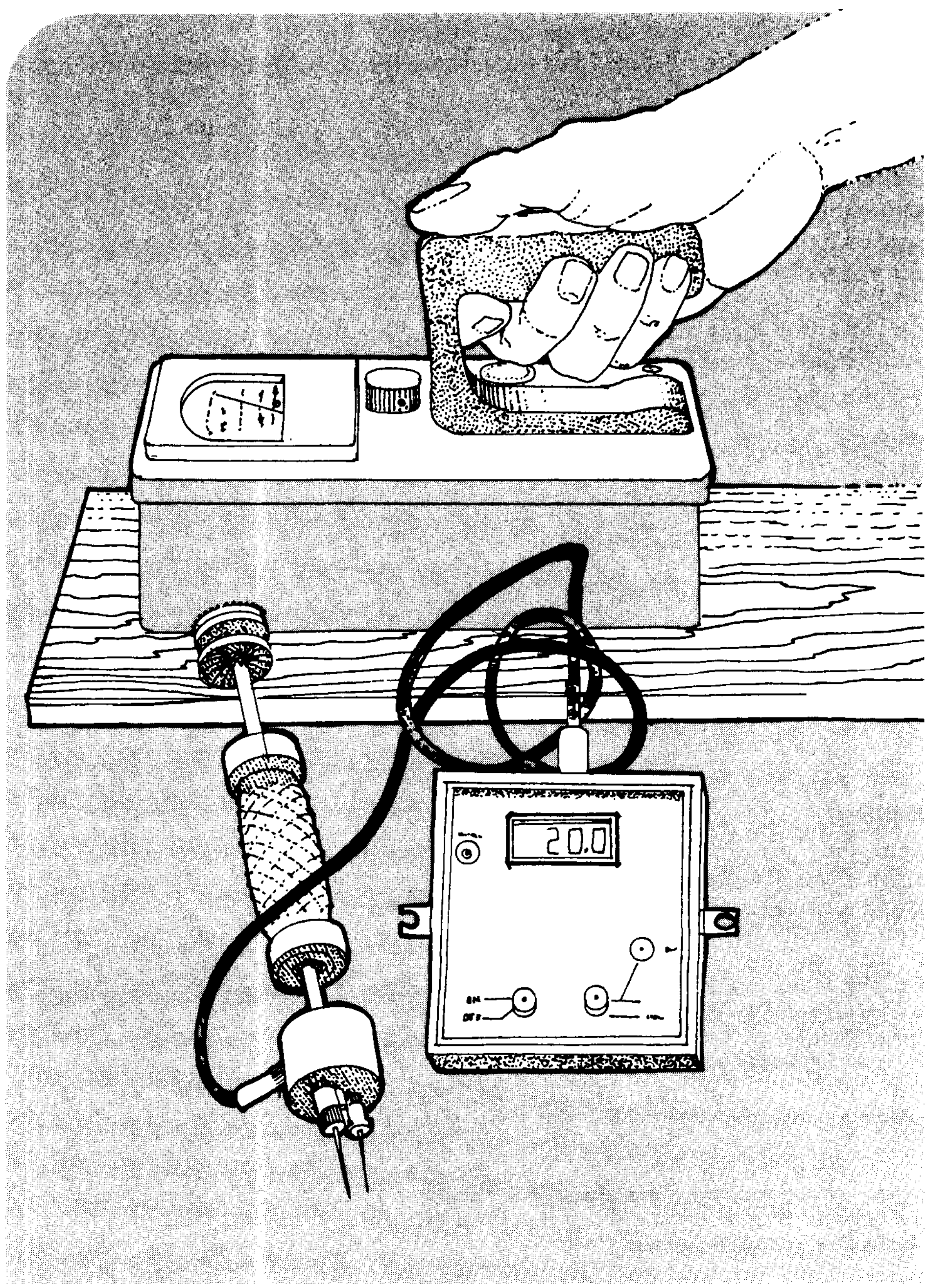

# Abstract

Electric moisture meters for wood measure electric conductance (resistance) or dielectric properties, which vary fairly consistently with moisture content when it is less than 30 percent. The two major classes of electric moisture meters are the conductance (resistance) type and the dielectric type. Conductance-t ype meters use penetrating electrodes that measure in a small volume, so moisture gradients may be deduced by repeated measurements at increasing depths. Dielectric-type meters use surface electrodes that do not puncture the wood surface, and can measure the moisture content of relatively dry wood. This paper describes these major types of meter and includes detailed information on the kinds of electrodes used with each type.

Readings of moisture meters are affected by such factors as wood species and temperature, chemical treatments, moisture distribution, and operator skill. This paper contains information for correcting for these factors and for minimizing potential errors.

Keywords: Moisture measurement, moisture meters, electric properties

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# Contents

# Electric Moisture Meters for Wood

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## Introduction

Moisture content affects most of the important properties of wood, and it can vary widely depending on the environment and history of the wood. Effective use of wood and wood-base materials, therefore, requires efficient and reliable methods of measuring wood moisture.

For relating wood properties to moisture content, the moisture content is defined as the weight of the water contained in the wood expressed as a percentage of the ovendry weight of the wood. Thus, the moisture content may range from zero for ovendry wood to over 100 percent when the water in the wood weighs more than the wood substance.

The two basic methods of determining wood moisture content are the ovendrying method and the distillation method. The ovendrying method is generally accepted for basic laboratory work and as a standard for calibrating other methods (American Society for Testing and Materials (ASTM) 1968). This method involves simply weighing the specimen before and after ovendrying to constant weight at 103° C. Because the quantities used for defining moisture content are measured directly, this method is the most precise known. However, it is physically impossible to remove all the hydroscopic water by heating without pyrolyzing the wood. For this reason, constant weight is defined as no further weight loss when a specimen is weighed to an accuracy of ± 0.2 percent at 2-hour intervals.

If wood has been treated or impregnated with chemicals, ovendrying moisture measurements may be inaccurate. An impregnant that is volatile at oven temperatures will evaporate during ovendrying, and the resulting weight loss can be misinterpreted as due to evaporated water. An impregnant that is nonvolatile will remain in the wood and so increase the apparent ovendry weight of the wood. For treated wood, the distillation method may be more accurate than ovendrying (ASTM 1968) for measuring moisture content. In this method, water is removed from the wood specimen in a closed system, in which the water is collected and measured directly. Any extraneous organic materials in the wood are dissolved out of the specimen by an organic solvent during the water extraction process. The distillation method is also more accurate than the ovendry method for some species that naturally contain large amounts of volatile materials other than water.

The disadvantages of these two basic methods of determining wood moisture are that they are time consuming (the drying period alone is at least 24 h), they require expensive apparatus and considerable skill in manipulation, and they destroy the specimen. These problems have prompted the search for other simpler and faster methods for measuring moisture content.

Some early methods, tried as substitutes for the ovendrying method, used humidity sensors or indicators to estimate wood moisture content from the humidity at the surface or inside the wood. Others used chemicals to extract water from a pulverized wood specimen, using various means to determine the amount of water adsorbed by the extracting chemical. The potential value of electric conductance as a moisture indicator became evident when Suits and Dunlap (1931) studied the dependence of electric conductance of wood on its moisture content.

A conductance-type (resistance-type) moisture meter differs from an ordinary ohmmeter only in the unusually high values of resistance (low conductance) that must be measured when checking wood with moisture content below about 10 percent. First attempts to develop a portable instrument capable of measuring such low conductance began in the late 1920's and led to the "blinker-type" meter. This device consisted of a neon lamp in parallel with a high-quality capacitor that was charged through the wood specimen as a series conductor. When the capacitor voltage reached the firing voltage of the lamp, the lamp conducted briefly, thereby discharging the capacitor and starting the process over again. The time required to charge the capacitor increased as the series conductance decreased, so the rate of flashing of the neon lamp indicated the electric conductance of the wood.

After the blinker-type meter, a high-resistance vacuum-tube bridge was developed that led to the modern direct-reading conductance-type moisture meters (Davies 1937). These instruments are basically conductance bridge circuits, using a wide range of standard resistors and a high-resistance electronic voltmeter to measure the bridge output. At about the same time as direct-reading conductance-type meters appeared on the market, dielectric-type meters were developed. These types of meter operate on the relationship between the dielectric properties and moisture content of wood.

To date, three types of electric moisture meter, each based on the fundamental relationship between moisture content and a different electric property, have been developed: the conductance-type (resistance-type), which uses the relationship between moisture content and direct current conductance; the power-loss type, which uses the relationship between moisture content and the dielectric loss factor of the wood; and the capacitance type, which uses the relationship between moisture content and the dielectric constant of the wood. The latter two types of meter are classed as dielectric types. Meters that use the relationship between moisture content and electric conductance have been referred to traditionally as "resistance-type" meters. However, it is conductance that increases with increasing moisture content, so wood technologists are beginning to use the more descriptive term "conductance-type" for these meters. Conductance is simply the reciprocal of resistance.

At present, there are several manufacturers of portable conductance-type meters and one manufacturer of portable power-loss-type meters in the United States. No purely capacitance-type portable meter is currently being marketed although one portable meter is, in effect, a combination of capacitance and power-loss types. This meter is called the capacitive-admittance-type meter.

In addition to portable meters, stationary meters are available that monitor the moisture content of lumber moving along a conveyor and mark or eject individual pieces that are outside of moisture specifications. Both conductance-type and dielectric-type automatic moisture meters are available; all use nonpenetrating electrodes. Typical systems are shown in figure 1. Systems are also available for monitoring the drying progress of lumber in a dry kiln. Such systems are based on the conductance principle (use of permanently installed penetrating electrodes) or on the alternating-current impedance of the lumber (use of electrodes placed in the kiln loads between lumber courses).

In the discussion that follows, the electric properties that provide the basis for electric moisture meters and the operating procedures for each type of meter will be described in more detail.

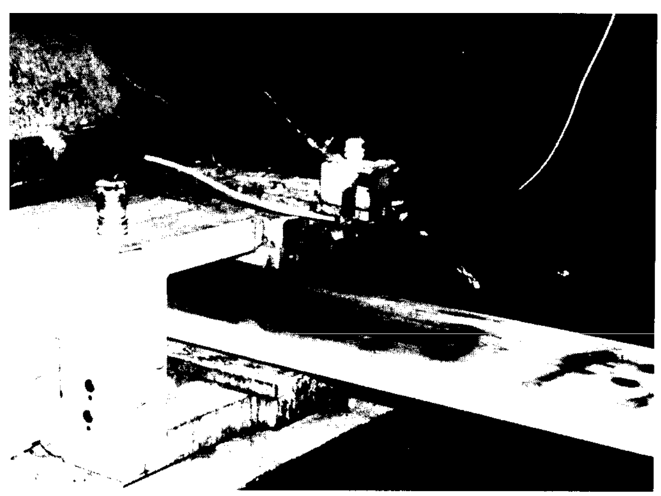

*Figure 1 — Typical installation of nonportable moisture meter for monitoring the moisture content of material moving along a conveyor. (M 143 064)*

# Electric Properties of Wood

The electric properties of wood that are important for electric moisture meters are direct current conductance (resistance) and the dielectric constant and loss tangent (power factor).

## Direct Current Conductance

Electric conductance is the property of a material that permits the flow of electric current through the material. The magnitude of conductance determines the current flow with a given potential difference or electromotive force across the conductor. In most cases, the magnitudes of conductance (or resistance), electromotive force, and current are related by a simple proportion known as Ohm's law.

### Effect of Moisture Content

The direct-current conductance (resistance) of wood varies greatly with moisture content below fiber saturation. As the moisture content decreases from fiber saturation (about 30 pct moisture, based on the dry weight of the wood) to the ovendry condition, the conductance decreases by a factor of over 10 million (table 1). In this range of moisture content, a roughly linear relationship exists between the logarithm of conductance and the logarithm of moisture content. At moisture content levels beyond fiber saturation, the electrical conductance correlates very poorly with moisture content. Increasing the moisture content from fiber saturation to complete filling of the capillary structure of the wood with free water typically increases the conductance by a factor of 50 or less. This is true even though most species at complete saturation contain well over 100 percent moisture content based on the ovendry weight of the wood. Typical values of resistance of Douglas-fir, measured at room temperature using a moisture meter electrode, are 22,400 megohms at 7 percent moisture content and 0.46 megohm at 25 percent moisture content. Corresponding data for other species and levels of moisture content are given in table 1. Values of conductance in microsiemens are reciprocals of the table data.

### Effect of Temperature

The electric conductance of wood increases as the temperature of the wood increases (Davidson 1958; James 1968). This is opposite to the effect of temperature on resistance in metals and suggests that in wood the mechanism of conduction is by charge carriers whose number or mobility is increased by thermal activity. Thus, the conduction of current by wood is likely to be at least in part ionic. For moisture levels above approximately 10 percent, the conductance of wood is roughly doubled for each increase in temperature of 10 °C.

### Effect of Grain Angle

The conductance of wood parallel to the grain is about double that of conductance perpendicular to the grain. Ratios of conductance perpendicular to the grain, in relation to the longitudinal value, are about 0.055 for radial and 0.50 for tangential.

## Dielectric Constant and Power Factor

The dielectric constant of a material is defined as the ratio of the capacitance of a capacitor, using the material as the dielectric, to the capacitance of the same capacitor with a vacuum (in practical usage, air) as the dielectric. In principle, the dielectric constant is a measure of how much electric potential energy (dipole moment per unit volume) is stored in the material when it is placed in a given electric field.

The dielectric power factor is a measure of the rate of dissipation of electric energy as heat within a dielectric material. When a dielectric material is placed in a constant electric field, it absorbs a certain amount of energy from the field and stores it as potential electric energy. With a perfect dielectric material, this energy is completely recoverable when the field is removed. In practice, however, some energy is lost in the store-recover cycle; this energy appears as heat within the dielectric material.

If the dielectric material is in an electric field that is oscillating at a constant frequency, the dielectric material will absorb and dissipate from the field power proportional to the product of the frequency and the loss factor. The power absorbed does not necessarily increase linearly or even monotonically with increasing frequency, however, because the loss factor may vary considerably with frequency (James 1974).

### Effect of Moisture Content

Dielectric constant increases with increasing moisture content. The effect of moisture content is much greater as the frequency of the applied field decreases (James 1974). There is a roughly linear relationship

Table 1 – The average electrical resistance along the grain of several species of wood at different levels of moisture content[1]

| Species of wood | Moisture content (pct) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| | Resistance (MΩ) | | | | | | | | | | | | | | | | | | |
| ***Conifers*** | | | | | | | | | | | | | | | | | | | |
| Baldcypress | 12,600 | 3,980 | 1,410 | 630 | 265 | 120 | 60 | 33 | 18.6 | 11.2 | 7.1 | 4.6 | 3.09 | 1.78 | 1.26 | 0.91 | 0.66 | 0.51 | 0.42 |
| Douglas-fir (coast region) | 22,400 | 4,780 | 1,660 | 630 | 265 | 120 | 60 | 33 | 18.6 | 11.2 | 7.1 | 4.6 | 3.09 | 2.14 | 1.51 | 1.10 | .79 | .60 | .46 |
| Fir, California red | 31,600 | 6,760 | 2,000 | 725 | 315 | 150 | 83 | 48 | 28.8 | 18.2 | 11.8 | 7.6 | 5.01 | 3.31 | 2.29 | 1.58 | 1.15 | .83 | .63 |
| Fir, white | 57,600 | 15,850 | 3,980 | 1,120 | 415 | 180 | 83 | 46 | 26.9 | 16.6 | 11.0 | 6.6 | 4.47 | 3.02 | 2.14 | 1.55 | 1.12 | .86 | .62 |
| Hemlock, eastern | – | 120,000 | 20,000 | 4,300 | 1,300 | 450 | 200 | 100 | 45.0 | 25.0 | 14.0 | 8.8 | 5.40 | 3.50 | 2.30 | 1.60 | 1.10 | .78 | .57 |
| Hemlock, western | 22,900 | 5,620 | 2,040 | 850 | 400 | 185 | 98 | 51 | 28.2 | 16.2 | 10.0 | 6.0 | 3.89 | 2.52 | 1.58 | 1.05 | .72 | .51 | .37 |
| Larch, western | 39,800 | 11,200 | 3,980 | 1,445 | 560 | 250 | 120 | 63 | 33.9 | 19.9 | 12.3 | 7.6 | 5.02 | 3.39 | 2.29 | 1.62 | 1.20 | .87 | .66 |
| Pine, jack | 450,000 | 52,000 | 9,500 | 2,800 | 1,000 | 440 | 210 | 110 | 60.0 | 35.0 | 21.0 | 13.0 | 8.80 | 5.80 | 3.80 | 2.60 | 1.80 | 1.30 | .98 |
| Pine, longleaf | 25,000 | 8,700 | 3,160 | 1,320 | 575 | 270 | 135 | 74 | 41.7 | 24.0 | 14.4 | 8.9 | 5.76 | 3.72 | 2.46 | 1.66 | 1.15 | .79 | .60 |
| Pine, red | 700,000 | 100,000 | 17,000 | 4,300 | 1,300 | 470 | 210 | 100 | 52.0 | 28.0 | 16.0 | 10.0 | 6.80 | 4.40 | 2.80 | 1.90 | 1.20 | .91 | .67 |
| Pine, white | 20,900 | 5,620 | 2,090 | 850 | 405 | 200 | 102 | 58 | 33.1 | 19.9 | 12.3 | 7.9 | 5.01 | 3.31 | 2.19 | 1.51 | 1.05 | .74 | .52 |
| Pine, ponderosa | 39,800 | 8,910 | 3,310 | 1,410 | 645 | 300 | 150 | 81 | 44.7 | 25.1 | 14.8 | 9.1 | 5.62 | 3.55 | 2.34 | 1.62 | 1.15 | .87 | .69 |
| Pine, shortleaf | 43,600 | 11,750 | 3,720 | 1,350 | 560 | 255 | 130 | 69 | 38.9 | 22.4 | 13.8 | 8.7 | 5.76 | 3.80 | 2.63 | 1.82 | 1.29 | .93 | .66 |
| Pine, sugar | 22,900 | 5,250 | 1,660 | 645 | 280 | 140 | 76 | 44 | 25.7 | 15.9 | 10.0 | 6.6 | 4.36 | 3,02 | 2.09 | 1.48 | 1.05 | .75 | .56 |
| Redwood | 22,400 | 4,680 | 1,550 | 615 | 250 | 100 | 45 | 22 | 12.6 | 7.2 | 4.7 | 3.2 | 2.29 | 1.74 | 1.32 | 1.05 | .85 | .71 | .60 |
| Spruce, black | 700,000 | 90,000 | 16,000 | 4,300 | 1,400 | 580 | 250 | 120 | 68.0 | 38.0 | 23.0 | 14.0 | 9.60 | 6.30 | 4.30 | 3.00 | 2.10 | 1.40 | 1.00 |
| Spruce, Sitka | 22,400 | 5,890 | 2,140 | 830 | 365 | 165 | 83 | 44 | 25.1 | 15.5 | 9.8 | 6.3 | 4.27 | 3.02 | 2.14 | 1.58 | 1.17 | .91 | .71 |
| ***Hardwoods*** | | | | | | | | | | | | | | | | | | | |
| Ash, black | 14,000 | 2,300 | 600 | 200 | 85 | 40 | 20 | 10 | 6.0 | 3.4 | 2.1 | 1.3 | .90 | .60 | .42 | .32 | .25 | .20 | .17 |
| Ash, white[2] | 12,000 | 2,190 | 690 | 250 | 105 | 55 | 28 | 14 | 8.3 | 5.0 | 3.2 | 2.0 | 1.32 | .89 | .63 | .50 | .44 | .40 | .40 |
| Aspen, bigtooth | 300,000 | 24,000 | 4,000 | 1,100 | 360 | 150 | 60 | 30 | 16.0 | 8.6 | 5.0 | 3.1 | 2.00 | 1.30 | .88 | .61 | .43 | .33 | .26 |
| Basswood[2] | 36,300 | 1,740 | 470 | 180 | 85 | 45 | 27 | 16 | 9.6 | 6.2 | 4.1 | 2.8 | 1.86 | 1.32 | .93 | .69 | .51 | .39 | .31 |
| Birch[2] | 87,000 | 19,950 | 4,470 | 1,290 | 470 | 200 | 96 | 53 | 30.2 | 18.2 | 11.5 | 7.6 | 5.13 | 3.55 | 2.51 | 1.78 | 1.32 | .95 | .70 |
| Birch, paper | 200,000 | 24,000 | 5,000 | 1,400 | 550 | 230 | 110 | 57 | 30.0 | 17.0 | 10.0 | 6.0 | 4.00 | 2.50 | 1.70 | 1.10 | .81 | .59 | .43 |
| Elm, American | 18,200 | 2,000 | 350 | 110 | 45 | 20 | 12 | 7 | 3.9 | 2.3 | 1.5 | 1.0 | .66 | .48 | .42 | .40 | .40 | .40 | .40 |
| Hickory[2] | – | 31,600 | 2,190 | 340 | 115 | 50 | 21 | 11 | 6.3 | 3.7 | 2.3 | 1.5 | 1.00 | .71 | .52 | .44 | .40 | .40 | .40 |
| Khaya[3] | 44,600 | 16,200 | 6,310 | 2,750 | 1,260 | 630 | 340 | 180 | 105.0 | 60.2 | 35.5 | 21.9 | 14.10 | 9.33 | 6.16 | 4.17 | 2.82 | 1.99 | 1.44 |
| Magnolia[2] | 43,700 | 12,600 | 5,010 | 2,040 | 910 | 435 | 205 | 105 | 56.2 | 29.5 | 16.2 | 9.1 | 5.25 | 3.09 | 1.86 | 1.17 | .74 | .50 | .32 |
| Mahogany *(Swietenia)* | 20,900 | 6,760 | 2,290 | 870 | 380 | 180 | 85 | 43 | 22.4 | 12.3 | 7.2 | 4.4 | 2.69 | 1.66 | 1.07 | .72 | .49 | .35 | .26 |
| Maple, sugar | 72,400 | 13,800 | 3,160 | 690 | 250 | 105 | 53 | 29 | 16.6 | 10.2 | 6.8 | 4.5 | 3.16 | 2.24 | 1.62 | 1.23 | .98 | .75 | .60 |
| Oak, northern red[4] | 14,400 | 4,790 | 1,590 | 630 | 265 | 125 | 63 | 32 | 18.2 | 11.3 | 7.3 | 4.6 | 3.02 | 2.09 | 1.45 | .95 | .80 | .63 | .50 |
| Oak, white | 17,400 | 3,550 | 1,100 | 415 | 170 | 80 | 42 | 22 | 12.6 | 7.2 | 4.3 | 2.7 | 1.70 | 1.15 | .79 | .60 | .49 | .44 | .41 |
| Philippine mahogany *(Shorea* Spp.) | 2,890 | 690 | 220 | 80 | 35 | 15 | 9 | 5 | 2.8 | 1.7 | 1.1 | .7 | .45 | .30 | .21 | .16 | .12 | .09 | .07 |
| Sweetgum | 38,000 | 6,460 | 2,090 | 815 | 345 | 160 | 81 | 45 | 25.7 | 15.1 | 9.3 | 6.0 | 3.98 | 2.63 | 1.78 | 1.26 | .87 | .63 | .46 |
| Tupelo, black[4] | 31,700 | 12,600 | 5,020 | 1,820 | 725 | 275 | 120 | 58 | 27.6 | 13.0 | 6.9 | 3.7 | 2.19 | 1.38 | .95 | .63 | .46 | .33 | .25 |
| Walnut, black | 51,300 | 9,770 | 2,630 | 890 | 355 | 155 | 78 | 41 | 22.4 | 12.9 | 7.3 | 4.9 | 3.16 | 2.14 | 1.48 | 1.02 | .72 | .51 | .38 |
| Yellow-poplar[4] | 24,000 | 8,320 | 3,170 | 1,260 | 525 | 250 | 140 | 76 | 43.7 | 25.2 | 14.5 | 8.7 | 5.76 | 3.81 | 2.64 | 1.91 | 1.39 | 1.10 | .85 |

[1]Resistance measured in megohms at 80 °F between two pairs of needle electrodes spaced 1-1/4 inches apart and driven to a depth of 5/16 inch. The reciprocals of these data are conductance in micro siemens.

[2]Exact species unknown.

[3]Known in the trade as "African mahogany."

[4]The values for this species were calculated from measurements on veneer.

between moisture content and logarithm of the dielectric constant at all frequencies, but the slope of the relationship increases as the frequency decreases (James 1974).

The power factor usually increases with increasing moisture content, but the reverse is true at some combinations of moisture content, temperature, and frequency. Power factor is a nonlinear function of moisture, temperature, and frequency, and exhibits maximum and minimum values at various combinations of these variables.

### Effect of Density

The dielectric constant of wood increases nearly linearly with increasing density, although a slightly concave upward trend is apparent as the moisture content of the wood increases.

The power factor of ovendry wood increases rapidly with increasing density up to a density of about 25 pounds per cubic foot; above this density the power factor increases only slightly. At higher moisture levels, the power factor-density relationship becomes slightly concave upward.

The loss factor, since it is the product of two quantities that increase with density, also increases with density.

### Effect of Temperature

The dielectric constant of wood increases with increasing temperature, except at very high moisture content where it is erratic and possibly reversed; the reversal could be related to the lowering of the fiber-saturation point at higher temperatures (James 1974). The increase in dielectric constant with increasing temperature indicates the presence of thermally activated mechanisms of polarization. These mechanisms probably are interracial polarization, where the external electric field causes ionic charge carriers to accumulate at internal discontinuities in the wood, and fixed dipole polarization, associated with orientation of polar cellulose molecules caused by the external field. Other mechanisms of polarization exist in wood, such as induced molecular dipole moment, but are influenced only slightly by temperature.

As stated earlier, the power factor is not a simple function of temperature but may increase or decrease as the temperature increases, depending on frequency and moisture content.

### Effect of Species

Most wood species with approximately equal density have similar electric properties, but there are exceptions. For example, silk-oak *(Grevillea robusta)* apparently contains unusually large concentrations of soluble salts or other electrolytes and has very unusual electric properties.

# Conductance-Type Moisture Meters

Portable conductance-type moisture meters are battery-operated, wide-range ohmmeters. Most models have a direct reading meter, calibrated in percent moisture content for one species and with correction tables for other species. A portable conductance meter is illustrated in figure 2.

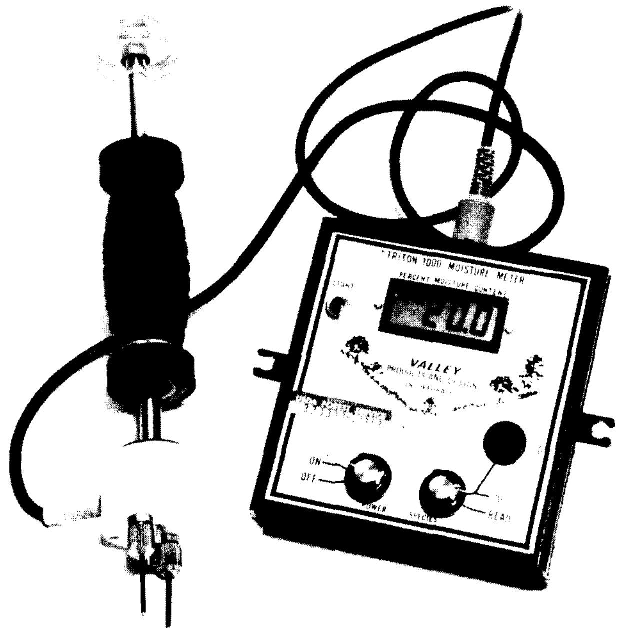

*Figure 2—A portable resistance-type moisture meter, with an electrode of two 1-inch pins. (M 870 131)*

To measure the electrical conductance of a wood specimen, the specimen must be arranged as an element in an electrical circuit. This requires electrical contact with the wood at two points, using a method of contact that produces consistent and meaningful results. Two types of electrode can be used: surface-contact or pin-type electrodes.

## Surface-Contact Electrodes

Surface-contact electrodes are not generally usable with conductance-type meters, except possibly on thin veneer, because of the conductance gradients associated with wood drying under normal conditions. With surface contacts, the generally drier and hence vastly more resistive surface dominates the measured conductance, and only readings of the dry surface are possible. In general, surface electrodes on opposite sides of a flat specimen indicate the moisture content of the driest layer of wood between the electrodes.

## Pin-Type Electrodes

Electrodes that penetrate the wood have greater applicability than surface-contact electrodes. Pin-type electrodes are widely used because of their simplicity. The simplest of these penetrating electrodes have poles consisting of nail-like pins that are driven into the wood. Electrodes that are screwed into the wood are in limited use.

When pin-type electrodes are driven into wood, the observed conductance is almost exclusively in the thin shell of wood that is in immediate contact with the pin. Neither the conductivity of the wood between the poles of the electrode nor the distance between the poles has any significant effect on the reading of a conductance-type moisture meter.

Pin-type electrodes are driven into the specimen from one side, so the measured conductance is nominally in a plane parallel to the surface of the specimen and not across its thickness. Thus, the flow of electric current is parallel to the planes of nearly equal moisture content, assuming no gross anomalies in moisture distribution. Because of the steep conductance gradients in wood drying under normal conditions, practically all the current flows through the wettest layer of wood that is in contact with both poles of the electrode. If the moisture content of the wettest wood in contact with one pole of the electrode differs from the moisture content of the wettest wood in contact with the other pole, the drier of the two loci will limit the current and thus be responsible for the reading. Thus, it is important to emphasize that the reading of a conductance-type moisture meter will be related to the wettest wood that contacts both poles of the electrode. Usually this wood is located right at the tips of the penetrating electrodes. This characteristic of conductance meters enables estimation of moisture content gradients since readings can be taken at various depths.

Wood of rectangular cross section that has been drying at a fairly constant rate and is drier throughout than fiber saturation will have a moisture distribution such that, at a depth of one-fourth to one-fifth of its thickness, the moisture content will be nearly equal to the average for the entire cross section. This is referred to as the "one-fourth to one-fifth thickness rule." The corresponding depth for circular cross sections is about one-sixth of the diameter. Electrode pins should therefore reach these depths in order to indicate average moisture content (ASTM 1968).

Conductance data for calibrating conductance-type moisture meters have been obtained with the current flowing parallel to the grain. Therefore, when using meters of this type, the electrode should be oriented so that the current flows parallel to the grain. If the readings drift, take the reading immediately after the electrode is driven into the specimen.

### Four-Pin Electrode

One type of moisture meter electrode uses four steel phonograph needles (pins) that extend about 8 millimeters (5/16 in) beyond their mounting chucks. Each pole of the electrode uses two pins. The poles are about 3 centimeters (1-1/8 in) apart, and the two pins comprising each pole are about 1.5 centimeters (1/2 in) apart. The electrode is composed of a plastic material, combining good mechanical strength and high electrical insulating value. A handle is attached for driving and extracting the electrode. The pin length is about one-fifth of the thickness of nominal 38-millimeter (2-in) dimension lumber, so the pin is suited for indicating the average moisture content for this thickness. The average moisture content of thinner material may be read by driving the pins to less than their full depth. Although most data for calibrating conductance moisture meters have been obtained using the four-pin electrode, its use in the field has declined in recent years, probably because of the greater convenience and versatility of the two-pin electrode.

### Two-Pin Electrode

Measuring the average moisture content of material thicker than nominal 38 millimeter (2-in dimension lumber) requires a pin longer than 8 millimeters. Most meter manufacturers fill this need with a two-pin electrode: each pin comprises one pole of the electrode and is about 25 millimeters long (1-in). To achieve the necessary strength, these pins are larger in diameter than the pins used in the four-pin electrode. Two pins are used instead of four to permit the larger pins to be driven and extracted more easily. A two-pin electrode is illustrated in figure 2; this electrode features a central retractable probe that moves a scale for indicating the depth of penetration of the pins.

Despite the larger diameter and consequent larger contact area of the pins used in the two-pin electrode, readings using this electrode are consistently lower (about 1/2 to 1 pct) than readings made using the four-pin electrode (James 1961). Apparently, doubling the contact area of a single pin is substantially less effective in increasing the net conductance than duplicating the contact area with a second pin. Thus, when using any two-pin electrode, a correction of 1 percent moisture content should be added when the indicated moisture content exceeds 15 percent, and when the meter is calibrated for a four-pin electrode.

At least one manufacturer of conductance-type moisture meters offers a two-pin electrode with pins about 7.5 centimeters (3 in) long for use on poles, bridge timbers, and other large material.

### Insulated-Pin Electrode

Some manufacturers offer electrodes with 25- or 75-millimeter (1 or 3 in) pins that are covered by a tough insulating resin except at the tip. These electrodes are useful when testing lumber with a high superficial moisture content, such as that caused by rain or dew. Superficial films of high moisture are rarely detrimental to the usefulness of the lumber. However, if the pin electrodes are not insulated, a conductance-type moisture meter would indicate the high surface moisture content and could cause the lumber to be rejected. Therefore, a valid estimate of average moisture content can be obtained by using insulated pins driven to the proper depth.

Even insulated pins cannot be used successfully on lumber that has free water on the surface because the water may follow the pins as they penetrate the wood, resulting in a very high, misleading moisture reading.

### Veneer Electrode

The electrode used with a conductance-type meter on veneer consists of a large number of needles, each about 3 millimeters (1/8 in) long, which are arranged into two groups; each group is one pole of the electrode. Normal calibration factors are assumed to be valid for this type of electrode.

### Substitute Electrodes

When the pins of the available electrode are too short to measure either the average or the core moisture content of a specimen with large cross section, two nails may be substituted for electrode pins. The nails should be driven to the proper depth and about the same distance apart as the pins on the standard electrode. The reading then can be obtained by touching the standard electrode pins to the nailheads. It should be emphasized, however, that the reading is not influenced by the distance between the nails.

When using two nails, as when using any two-pin electrode, a correction of 1 percent should be added when the indicated moisture content is over 15 percent.

### Permanent Electrodes

It is sometimes necessary to monitor the moisture content of a specimen of wood in a relatively inaccessible place. A simple and convenient way to do this is to drive electrode pins into the specimen, leave them in place, and bring wires attached to the electrodes out to the moisture meter. This procedure is used in some dry kiln monitors. This method has a serious problem, however, in that the permanent electrodes give erratic and unreliable data after a few hours, especially when the moisture content of the specimen is in the upper range of readability of the meter. However, when the moisture content of the specimen is no greater than about 15 percent, permanent electrodes are as reliable as freshly implanted electrodes.

## Useful Range of Conductance-Type Meters

The useful range of conductance-type moisture meters is from about 7 to about 30 percent moisture content; only approximate qualitative readings may be obtained on wood with over 30 percent moisture content. The lower limit results from the difficulty in measuring the very small conductance (high resistance) involved, and the upper limit results from the fact that conductance is only a weak and erratic function of moisture content greater than fiber saturation.

# Dielectric-Type Moisture Meters

The two basic types of dielectric moisture meter are the capacitance and power-loss meters. A third type, usually referred to as the capacitive-admittance type, is essentially a combination of capacitance and power-loss types. In the trade, all dielectric meters are sometimes referred to as "capacity-type" or "radiofrequency-type" meters; neither term directly applies to dielectric meters in general.

## Capacitance Type

Capacitance-type moisture meters use the relationship between moisture content and dielectric constant. The wood specimen is penetrated by the electric field associated with the capacitor of the frequency-determining circuit of an oscillator when the electrode of the meter contacts the wood. The frequency of the oscillator is changed according to the effect of the specimen on the capacitance of this capacitor or, in other words, according to the dielectric constant of the specimen. A frequency discriminator generates a signal, read on a meter, proportional to the changes in frequency. Using the relation between dielectric constant and moisture, the meter can be calibrated to read moisture content. Because of technical problems and high cost, this type of meter is not at present being manufactured commercially.

## Power-Loss Type

Power-loss type meters use the relation between moisture content and loss factor. The wood specimen is penetrated by the electric field radiating from an electrode that is coupled to a low-power oscillator in the meter. Power absorbed by the specimen loads the oscillator and reduces its amplitude of oscillation, which is in turn indicated by the meter dial. Since the loss factor depends on moisture content, the meter dial can be related to percent moisture.

A portable power-loss type moisture meter is illustrated in figure 3.

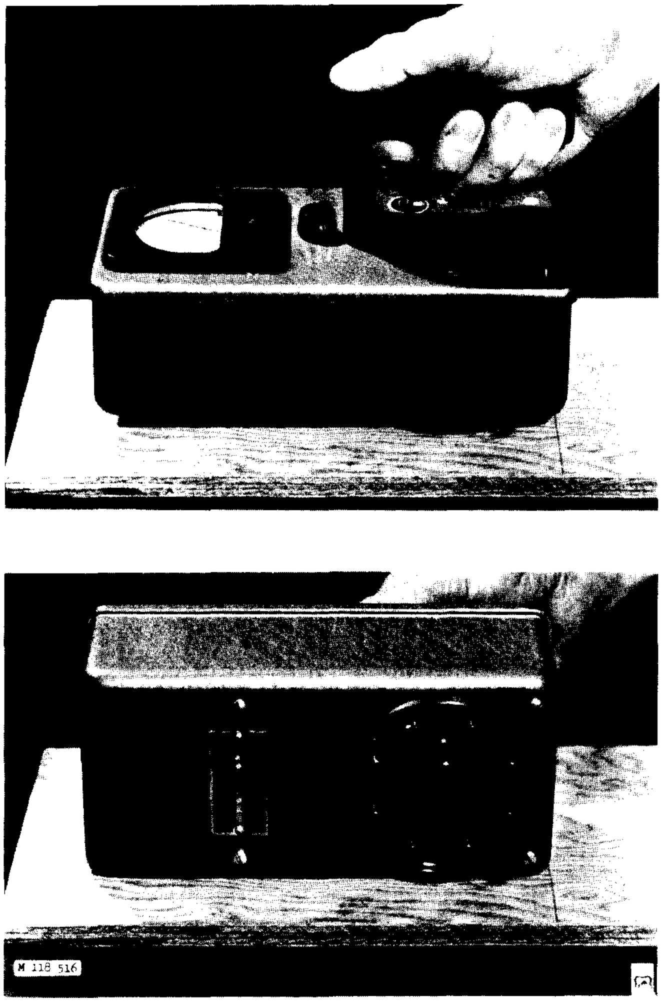


*Figure 3—A dielectric power-loss type moisture meter. (ZM 118 516)*

## Capacitive Admittance Type

The electrode of this meter is a capacitive element in a resistance-capacitance bridge circuit. When a wood specimen contacts the electrode, its capacitance and losses (admittance) are increased so that the bridge is unbalanced in proportion to the dielectric constant and loss factor of the specimen. The meter dial reads the amount of bridge imbalance, which can be related to the moisture content of the wood specimen causing the imbalance.

A portable capacitive admittance meter is shown in figure 4.

## Electrodes

Electrodes for dielectric-type meters are nonpenetrating. They vary in design according to particular applications but are not interchangeable for use with one instrument, as are electrodes for conductance meters. The electrode of a dielectric meter is an integral part of the instrument.

### Rough Lumber Electrode

On portable meters, this electrode consists of a number of short, spring-loaded rods with the exposed ends rounded and mounted in a circular plastic plate about 7.5 centimeters (3 in) in diameter. As the electrode is pressed into contact with the surface of the specimen, the spring-loaded rods are pushed into their mounting sockets in the plastic plate. Because of the restraining action of the springs, each rod maintains firm contact with the specimen surface. Thus, the rods adjust to irregularities in the surface, making the calibration of the meter nearly independent of the shape of the surface.

A modification of the rough lumber electrode consists of a single spring-loaded metal disk, about 25 millimeters (1 in) in diameter, surrounded by a circle of smaller but similarly spring-loaded metal disks. This arrangement is mounted on a plastic plate about 9 centimeters (3-1/2 in) in diameter.

The electric field from rough lumber electrodes penetrates about 2 centimeters (3/4 in) into the specimen, so that specimens up to about 4 centimeters thick (1- 1/2 in) may be used. However, when any surface-contact electrode is used with a dielectric meter, the surface layers of the specimen have a predominant effect on the meter readings, simply because the electric field is stronger near the electrode. This effect may be very pronounced when readings are made on wood with typical residual drying gradients. High moisture content material as little as one-eighth inch below the specimen surface may not be properly represented in the meter reading (Mackay 1976).

### Smooth Surface Electrode

The quadrant-type electrode gives slightly higher precision but is usable only on smooth, plane surfaces. This electrode consists of the four quadrants of a 75-millimeter disk, separated slightly and independently

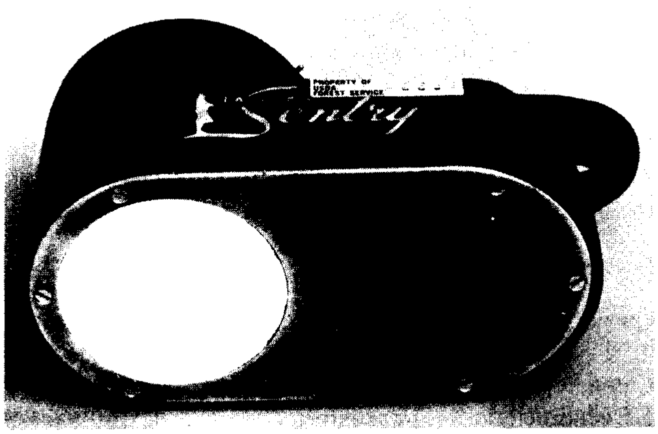

Figure 4—A dielectric capacitive admittance-type moisture meter. (M 141 438; M 141 439)

free to move slightly, mounted on a plastic plate. The field penetration of this electrode is about 25 millimeters.

### Veneer Electrode

This electrode consists of several concentric rings, all in one plane, mounted on a plastic plate about 75 millimeters in diameter. The field penetration of this electrode is about 2 millimeters. When measuring the moisture content of material thinner than 3 millimeters (1/8 in), it may be important to consider the material on the other side of the specimen. If the backup material is metal or a high-loss dielectric material, the reading of the moisture meter will probably be too high. It is best to use a low-loss backup material, such as rigid polystyrene foam.

### Thick-Specimen Electrode

The electrode for thick specimens consists of a ring of spring-loaded metallic disks surrounding a somewhat larger single disk in the center. This electrode is similar to the electrode described earlier for rough lumber but is scaled up in size, so the field penetrates about 50 millimeters (about 2 in). We again emphasize, however, that the meter registers a much smaller response to material 2 inches from the electrode than to material near or in contact with the electrode.

### General Purpose Electrode

This electrode consists of a circular disk that in use is separated from the specimen by 2 or 3 millimeters of low-loss insulation. This separation makes the surface condition of the specimen less influential, so the electrode is usable on either rough or smooth surfaces.

## Useful Range of Dielectric Moisture Meters

Dielectric moisture meters will read down to zero moisture, although the precision of the meters is reduced at very low moisture levels. Presently available power-loss meters have an upper range limit of about 15 to 30 percent moisture, depending on the wood species. The most precise operating range of the capacitive admittance meter is under 30 percent moisture content, but this meter can give qualitative readings at moisture levels greater than 30 percent.

# Accuracy of Moisture Meters

The accuracy of an electric moisture meter in good condition is never limited by the ability of the meter to respond precisely to the fundamental electrical property of wood on which its calibration is based, nor by the precision to which the dial can be read. The accuracy of a meter is limited by the influence of factors other than moisture content on the readings of the meter, insofar as these factors are unknown or not properly taken into account.

One such factor is the calibration of the meter. This is usually considered the responsibility of the manufacturer, and the user accepts the calibration data supplied with the meter. The accuracy of calibration, especially in regard to sampling and specimen control, is usually unknown to the user. Unless the user is willing to run an involved calibration procedure (James 1961, 1964), the influence of this factor is uncontrollable.

However, some factors that affect meter readings can be controlled by the user. The principal factors other than moisture that affect the readings of electric moisture meters are adequacy of sample specimen characteristics (species, density, moisture distribution, thickness, and temperature), electrode contact, grain direction, chemicals in the wood, weather conditions, and skill of operator.

## Adequacy of Sample

If all individual pieces in a lot of lumber were at the same moisture content and moisture meters gave the same readings on all wood at the same moisture content, the moisture content of the entire lot could be determined by a single reading. But the moisture content of any lot varies from piece to piece, the moisture content of every piece varies from point to point throughout the piece, and moisture meters give various readings on different specimens even at the same actual moisture content. For these reasons, an accurate estimate of the average moisture content of the lot requires more than one reading. A reading could be made on every piece in the lot, but usually the same information can be obtained for less cost by making readings on a smaller number of pieces, i.e., on a sample, properly selected from the lot.

Proper sampling entails selecting specimen pieces in such a way that in total they represent the lot without bias, and selecting a sufficient number of specimens to reduce the influence of variability to an acceptable level (Fell and Hill 1980; Freese 1967).

### Selection of Specimens

If the sample is unbiased, the average of readings on the sample will differ from the average of all possible readings on the lot only because of chance, not because of some consistent effect of the sampling method. This condition can be assured if the individual specimens are selected from the lot at random; thus, every piece in the lot has an equal chance of being in the sample.

A lot of lumber frequently consists of a number of subunits, such as kiln loads or forklift packages. Under these conditions, an unbiased sample usually can be selected most easily by a process called stratified random sampling (Freese 1967). The lot is divided into any number of roughly equal parts on the basis of some index of similarity (such as same kiln load), and two or more specimens are randomly drawn from each part. If the parts are not equal, the number of specimens from each part should be proportional to the number of individuals in the part. Again, the basic requirement of stratified random sampling is that all individual pieces have the same probability of being included in the sample.

### Number of Specimens

The number of specimens required for the sample depends on the level of accuracy desired and the variability of the data.

Although the level of accuracy is arbitrary, a reasonable and practical goal is to obtain a probability of 0.95 that the sample average is within 1.0 percentage point of the average of all possible readings on the lot. Accepting this, the required sample size depends only on the variability of the data.

In general, the variability of the data is unknown and can be estimated only from readings on a sample. The problem therefore is to draw an unbiased sample of arbitrary size and to determine from the observed variability of this sample whether more specimens are needed. Because statistically ideal computation of variability and sample size is too cumbersome for routine inspection of lumber, I suggest the following procedure for approximating sample size:

(1) Draw an unbiased sample of about 20 specimens and record one reading from each; take all readings 50 centimeters (approximately 2 ft) or more from the end of the piece.

(2) Find the “range” by subtracting the smallest reading from the largest, square this difference, and divide it by 4.

The resulting number is an estimate of the required sample size (Freese 1967). If this number is larger than 20, additional specimens are necessary to meet the desired standard of accuracy. If stratified sampling is used, this method may slightly overestimate the variance, so the estimate of sample size will be conservative.

If the lot to be inspected is quite small, it may be less costly to read every individual piece in the lot than to be concerned about proper sampling. If the lot is only a few pieces, two or more readings should be made at random on each piece. The same basic rules of sample size apply even to readings on a single specimen, except that using range as an estimate of variability is rather unreliable for small sample sizes. On the other hand, concern about sample size on a single specimen is rather academic, inasmuch as more readings than statistically required may be obtained in less time than it takes to estimate the required sample size.

## Specimen Characteristics

The characteristics that affect meter readings are species, density, moisture distribution, thickness, and temperature.

### Species

At a given moisture content, both the conductance and dielectric properties of wood depend on species (James 1961, 1964). In regard to conductance, species differ in structure and electrolyte concentration; in regard to dielectric properties, species vary with these same factors and also with density. Consequently, corrections for species should be made when the necessary correction data are available.

If species corrections are not available, conductance meters may be used for approximate readings because species corrections are usually less than 2 percent, especially for native North American-grown species. Dielectric meters may also be used by assuming the calibration for a species with a density similar to that of the specimens being tested, but the results will be reliable only as rough approximations. When a single species correlation is applied to several species in a commercial group, the readings may be biased and less precise than if each species were considered separately.

### Density

The readings of conductance meters are practically independent of specimen density. In contrast, the readings of dielectric meters are affected by the density of the specimens. A substantial part of the species corrections for dielectric meters is actually a correction for density. The species correction must be related to the average density of the species; any single moisture determination will be in error to the extent that the density of the specimen deviates from the average for its species (or more precisely, the average of the sample used for calibration of the meter). The American firm that manufactures power-loss meters provides two species corrections for some widely used species, one for high-density specimens and the other for low-density specimens. However, even if specimen density could be determined easily and reasonably accurately, available information on the effect of density on electric properties is inadequate to permit more than an approximate correction to be made.

### Moisture Distribution

High surface moisture, such as from rain or dew, forms a surface layer of high conductance and dielectric constant and loss factor. In general, superficial moisture causes excessively high readings in electric moisture meters of any type.

The average moisture content of a specimen with high superficial moisture may be read using a conductance-type meter equipped with an insulated pin electrode. If free water is standing on the surface, however, false readings are likely even with insulated pins.

Uneven moisture distribution along the length or width of a specimen may also result in meter readings that are grossly different from the true average. For this reason it is advisable, when individual readings are important, to make more than one determination on a given specimen.

Because of accelerated end-grain drying near the ends of specimens, moisture meter readings should be taken no closer than 50 centimeters from the end or at the lengthwise midpoint of the specimen, whichever is closest to the end of the specimen.

Moisture gradients in wood that is drying may differ greatly from the expected form. Consequently, readings of conductance meters at one-fourth to one-fifth of the wood's thickness may differ greatly from the average moisture content of the cross section. This situation may be recognized by reading the meter as the electrode pins are driven progressively into the specimen. Deviation from a smooth increase in reading with deeper penetration or a reading over 30 percent moisture content near the center suggests that "the one-fourth to one-fifth thickness rule" cannot be considered reliable (Skaar 1964).

Irregular drying gradients have unpredictable effects on the readings of dielectric meters, as the reading is the integrated effect of all the specimen material penetrated by the field. The moisture content of the material nearest the electrode has a predominant effect on the reading; in extreme cases (such as wet surfaces mentioned earlier), the reading could differ greatly from the average moisture content.

### Thickness

The problem of specimen thickness is related to that of moisture distribution or gradient. If the specimen has a uniform moisture content, excessive thickness does not affect the accuracy of the meter reading. When specimens are drying, moisture gradients must be taken into account. To obtain a valid reading of average moisture content, the depth of the reading must be related to the thickness of the specimen. Thus, it is necessary for the pins of conductance meter electrodes to be long enough to reach one-fifth to one-fourth of the thickness of the specimen, and the field from dielectric meter electrodes should penetrate essentially undiminished to the middle of the specimen (which is never actually achieved in practice). With both types of meter, the electrode should be selected to match the specimen thickness as nearly as possible.

If dielectric meters are used on specimens that are much thinner than those used to calibrate the meter, the readings will be too small. As mentioned earlier, the material behind thin specimens may also affect the reading.

### Temperature

As the temperature of wood increases so does its electrical conductance, and vice versa (Davidson 1958; James 1968, 1974; Keylwerth and Noack 1956). Temperature corrections should be made when using a conductance-type meter on specimens that are warmer than 90 °F or cooler than 70 °F. The amount of correction depends on both temperature and moisture content, so it is best to determine the correction from a chart (fig. 5). If a chart is not available, a rough correction can be made by subtracting 1 percent moisture content from the reading for every 20 °F the specimen temperature is above the calibration temperature specified by the manufacturer, and adding 1 percent for every 20 °F the specimen temperature is below the calibration temperature.

The effect of temperature on power loss and capacitive admittance is more complicated than its effect on conductance, so temperature corrections for these meters are not as simple as for conduct ante meters. Temperature corrections for power-loss and capacitive admittance meters can be made using charts, such as shown in figures 6 through 8, or special tables that provide readings corrected for temperature (Bramhall and Salamon 1972).

When using any type of electric moisture meter, the meter indication should first be corrected for temperature, and then the established room temperature-species corrections or calibration factors should be applied.

Temperature of the lumber also affects the calibration of in-line systems for monitoring moisture of lumber moving along conveyors. The limit settings should be adjusted for the temperature of the wood being monitored.

## Other Factors

In addition to specimen characteristics, meter readings are influenced by the contact of the electrodes with the specimen, orientation of the electrodes relative to specimen grain, treatments used to preserve specimens as well as adhesives and finishes, weather conditions, and skill of the operator.

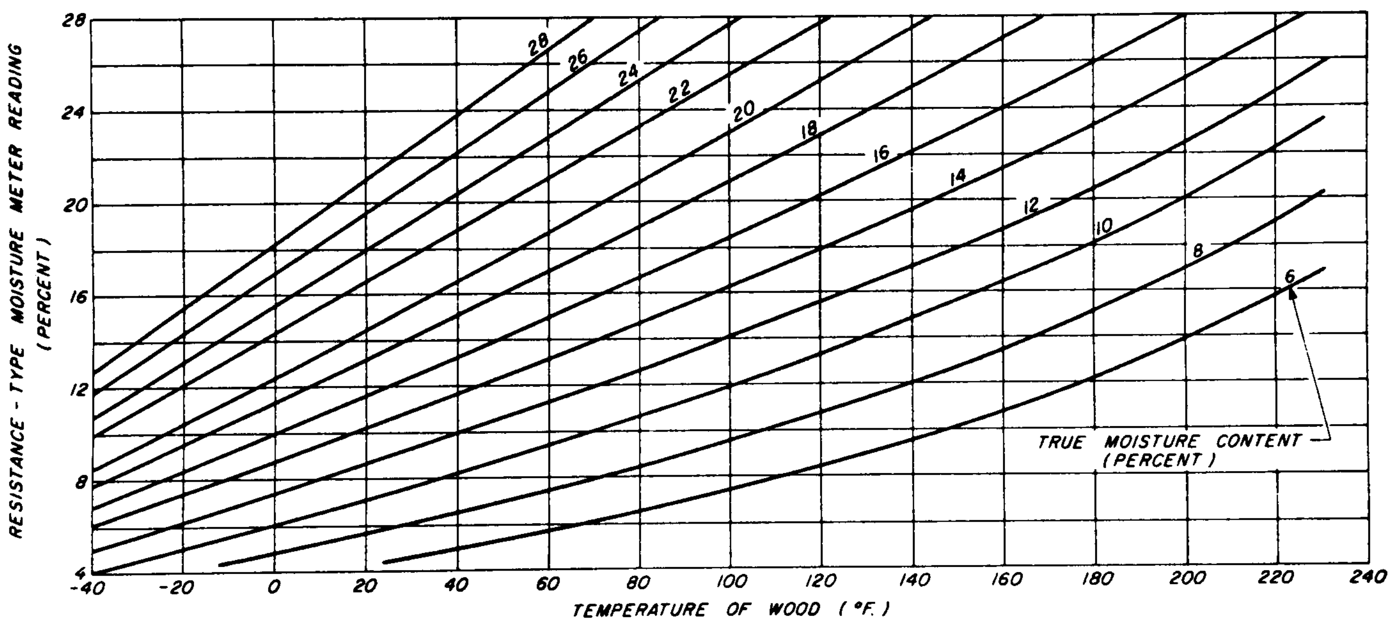


*Figure* **5—** *Temperature corrections for reading of conductance-type moisture meters, based on combined data from several investigators. Find meter reading on vertical left margin, follow horizontally to vertical line corresponding to the temperature of the wood, and interpolate corrected reading from family of curves. Example: If meter indicated 18 percent on wood at 120 °F, the corrected reading would be 14 percent. This chart is based on a calibration temperature of 70 °F. For other calibration temperatures near 70 °F, adequate corrections can reobtained simply by shifting the temperature scale so that the true calibration temperature coincides with 70 °F on the temperature scale. (M 76476 F)*

### Electrode Contact

For accurate readings, the electrode pins of the conductance meter must be driven to their proper depth into sound wood, and the surface electrodes of the dielectric meter must be pressed firmly against the specimen. When a dielectric meter is used, the specimen should be larger than the electrode; on all sides of the meter, the amount of wood to spare should at least equal the specimen thickness. With all meters, only sound wood free of decay, knots, and other defects should be in actual contact with the meter electrode.

### Grain Direction

Grain direction has no effect on the readings of dielectric meters because the electrodes are symmetrical. With conductance meters, however, the electrode should be oriented whenever possible so the current flows parallel to the grain. At moisture levels below about 15 percent, the effect of grain direction is negligible. At moisture levels above 20 percent, readings across the grain may occasionally be as much as 2 percent lower in moisture content than readings parallel to grain.

### Chemical Treatments, Adhesives, and Finishes

Wood that has been treated with salts for preservative or fire-retarding purposes or that has been in prolonged contact with seawater will generally have higher conductance, dielectric constant, and loss factor than untreated wood with the same moisture content. Consequently, electric moisture meter readings on treated wood will generally be too high. The error is usually negligible when the wood is below about 8 percent moisture content and increases with increasing moisture content. At moisture levels above 10 to 15 percent, the error grows rapidly and erratically, making correction impossible. Oilborne organic preservatives, such as creosote and pentachlorophenol, do not significantly affect the readings of electric moisture meters (James 1966).

Some types of glue used in plywood are electric conductors and may therefore affect the readings of electric moisture meters (Bell and Krueger 1949). The effect of plywood gluelines on the reading of a conductance meter may be determined by observing the meter reading as the electrode pins are driven into and then through the first ply. If the the reading increases abruptly as the pins contact the glueline, readings on that plywood will be unreliable. If no such effect is noted, the glue will not affect the readings.

Finishes rarely affect the readings of electric moisture meters. If it is suspected that a resin or metallic finish may be electrically conductive, the reading may be obtained using a conductance meter with insulated pins. The conductivity of the finish may be checked by pricking the finish film with electrode pins; a high moisture reading indicates a conductive finish, and no reading indicates a nonconductive finish.

Doors, tabletops, or other panel products that include a metal lamination to provide resistance to heat, fire, or x-rays are likely to give false readings with electric moisture meters.

### Weather Conditions

If electric moisture meters are used in foggy or rainy weather or are moved from cool surroundings into warmer, more humid surroundings, films of moisture may form on parts of the meter. These films may then provide leakage paths that seriously affect the operation of the meter. Usually these conditions may be recognized by difficulty in adjusting or balancing the meter, erratic or unstable zero settings, or no response from the meter when taking readings on material at low moisture levels.

### Skill of Operator

Electric moisture meters are relatively easy to operate. However, the accuracy and reliability of the readings do depend on the care exercised by the operator. Important considerations are careful adjustment of the meter controls, proper application of necessary correction factors, proper application of the electrode, attention to the condition of the instrument, and correct reading of the meter. Finally, the operator should select specimen material carefully to achieve the real objectives of the moisture measurements efficiently.

## Maintenance of Moisture Meters

The principal item of maintenance is replacement of defective or exhausted components of the instrument. Recalibration is rarely needed, especially with conductance meters, but the calibrations should nevertheless be checked periodically using standards supplied by the meter manufacturers. Dielectric meters are usually provided with a built-in standard for checking calibration.

Most portable electric moisture meters are powered by self-contained batteries. Dry batteries commonly will last for 6 months to a year with average use, but they should be replaced when adjustment controls must be set near the limits of their travel in order to adjust the meter correctly. Rechargeable batteries should be charged routinely. Vacuum tubes used in the older moisture meters are operated far below their rated power and will normally give years of service. Occasional replacements may be required. Electronic components other than tubes and batteries may occasionally fail and should be replaced only by a competent technician. The pins of conductance meter electrodes necessarily receive hard usage, and it is not uncommon for them to bend or break in use. It is advisable to have spare pins and the installation tools in the meter case. The electrode of any type of moisture meter should be kept clean to assure accuracy of the readings. The meter should always be handled carefully because rough handling can damage such fragile components as the meter movement or vacuum tubes.

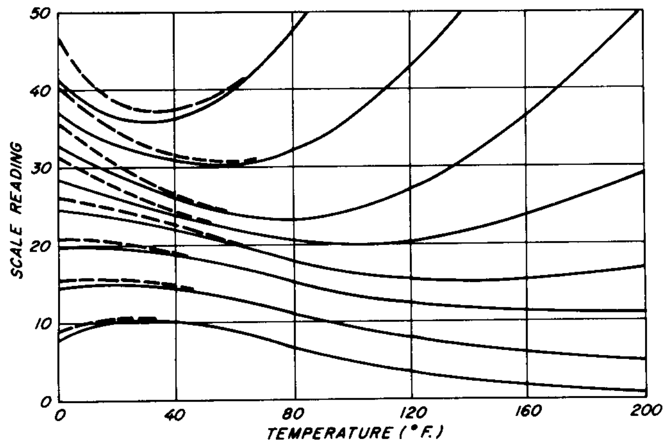


*Figure 6—Approximate temperature corrections for readings of power-loss-type moisture meters; data taken using a Moisture Register model L. Locate the point whose coordinates are the observed scale reading and the specimen temperature, and trace back parallel to the curves to the calibration temperature of the meter (usually 80 °F). The vertical coordinate here is the corrected scale reading, which is then converted to moisture content using the usual species conversion tables. Solid lines are for the meter itself at room temperature; dotted lines are for the meter at the same temperature as the specimens. (M 134 523)*

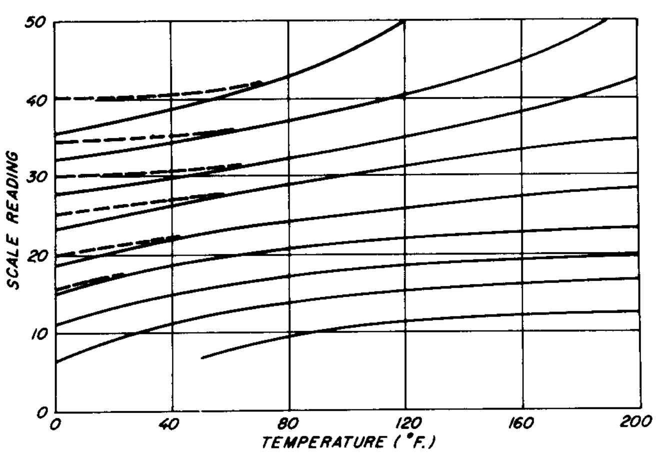


*Figure 7—Approximate temperature corrections for capacitive admittance meter; data taken using a "Sentry" hand meter with calibration setting of 20 or greater.* Chart is used as indicated for figure 6. (M 134 527)

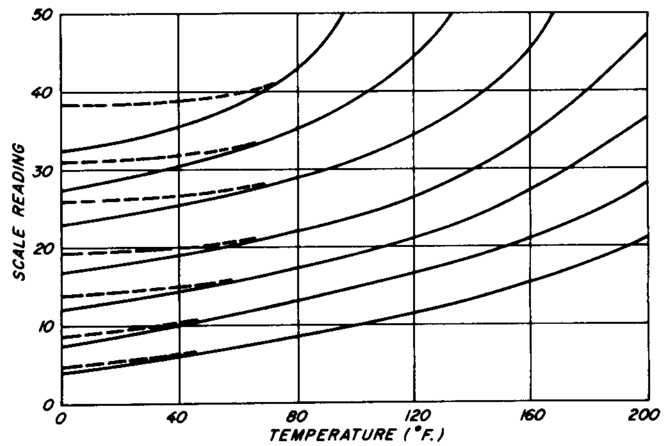


*Figure 8—Approximate temperature corrections for capacitive admittance meter; data taken using a "Sentry" hand meter with calibration setting of 15 or less.* Chart is used as indicated for figure 6. (M 134 530)

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