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ELECTRIC MOISTURE METERS FOR WOOD

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ELECTRIC MOISTURE METERS FOR WOOD¹

By

WILLIAM L. JAMES, Physicist

Forest Products Laboratory,² Forest Service
U.S. Department of Agriculture

Summary

Common methods of measuring the moisture content of wood are described briefly, and a short historical account of the development of electric moisture meters is given.

Electrical properties of wood are discussed briefly, and the basic operation of the resistance type and the radio-frequency types of moisture meter is outlined. Data relating the electrical resistance and moisture content of various species of wood are also presented.

A list of manufacturers and suppliers of electrical moisture meters is included.

Introduction

Most of the important properties of wood depend considerably on its moisture content, and the moisture content of wood can vary widely depending on its environment and history. For this reason, effective use of wood and wood-base materials 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 oven-dry

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weight of the wood. Thus the moisture content of wood may range from zero for oven-dry wood to over 100 percent when the water in the wood weighs more than the wood substance.

The oven-drying method of measuring the moisture content of wood is generally accepted for basic laboratory work, or as a standard for calibrating other methods. This method involves simply weighing the specimen before and after oven-drying. Because the quantities used for defining moisture content are measured directly, this method is the most precise known. Two basic assumptions, however, are made: (1) That the water is completely removed by oven-drying, and (2) that no material other than water is removed by the oven-drying. If the weighings are carefully made and care is taken to prevent significant regain of moisture by the oven-dry wood as it is weighed, the accuracy of the oven-dry method is limited only by the two basic assumptions mentioned above. In most instances, the expected errors in oven-dry moisture determinations are substantially less than 1 percent.

If wood has been treated or impregnated with various materials, oven-drying moisture measurements may be inaccurate. If the impregnant is volatile at oven temperatures, it will be evaporated and the resulting weight loss can be misinterpreted as due to evaporated water. If the impregnant is nonvolatile, it remains in the wood and increases the apparent oven-dry weight of the wood.

A common volatile impregnant is the oil used to carry dissolved preservatives into the wood. When these oils are present in wood, the moisture content may be measured using the distillation method. Here the wood specimen is fragmented and a weighed quantity of the fragments is placed in a flask of boiling toluene. The flask is connected to a closed system that includes a water-cooled condenser. The toluene plus the volatile materials in the wood evaporate and are condensed into a container in another part of the system. The water separates from the oil in this container and is measured directly. The oil and oil-soluble preservatives that do not vaporize are extracted from the wood by solution in the hot toluene. If the original weight of oil in the wood is a significant fraction of the oven-dry weight of the wood, it may be necessary to oven-dry the specimen fragments to remove the toluene to obtain the true oven-dry weight.

The distillation method is also more accurate than the oven-dry method on some species that naturally contain large amounts of volatile materials other than water.

These two basic methods of determining wood moisture have the disadvantages of being time consuming, requiring considerable skill in manipulation, and destroying the specimen. This prompted the search for other methods that were simpler and faster.

One method tried was to confine a strip of paper whose color indicated the relative humidity of its surroundings in contact with the wood; thus, the color of the paper

indicated roughly the moisture content of the wood. Another method involved pulverizing the specimen and mixing it with a chemical that generated a gas when reacting with water. When this reaction took place in a closed container, the chemical extracted the water from the wood and the moisture content of the wood was determined by measuring the gas pressure produced inside the container. Another method was to place the specimen in a small closed container in which a humidity-sensing element was mounted. The relative humidity inside the container, as measured by the sensing element, was related to the moisture content of the wood. A variation of this method involved boring a hole in the specimen and using a small pump to circulate air into the hole past a humidity-indicating chemical or sensor.

The potential value of electrical resistance as a moisture indicator became evident when studies were made of the electrical properties of wood (13, 14).³ It was found that the electrical resistance of wood generally depended on its moisture content, so a measure of electrical resistance could be used to indicate moisture content.

A resistance-type moisture meter differs from an ordinary ohmmeter only in the unusually high values of resistance that must be measured when checking wood below about 10 percent moisture content. First attempts to develop a portable instrument capable of measuring these high resistances began in the late 1920's and led to the "blinker-type" meter (15, 16, 17,18). This device consisted of a neon lamp in parallel with a high-quality capacitor that was charged through the wood specimen as a series resistor. 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 resistance increased, so the rate of flashing of the neon lamp indicated the electrical resistance of the wood.

Later, a high-resistance vacuum-tube bridge was developed that led to the modern direct reading resistance-type moisture meters (3). These instruments are basically Wheatstone bridge circuits using a wide range of standard resistors and a vacuum tube voltmeter as the bridge balance detector.

At about the same time as direct reading resistance-type meters appeared on the market, the radio-frequency-type meter was developed. This type of meter operated on the relationship between the dielectric properties and moisture content of wood.

An instrument designed to measure the moisture content of material moving along a conveyor chain and to mark or eject automatically material of improper moisture content became available about 1950.

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Underlined numbers in parentheses refer to Bibliography at the end of this report.

Thus, three types of electric moisture meter, each based on a different fundamental relationship, have been developed: **(1)** The resistance type, which uses the relationship between moisture content and direct current resistance; **(2)** the radio-frequency power-loss type, which uses the relationship between moisture content and the dielectric loss factor of the wood; and **(3)** the capacitance type, which uses the relationship between moisture content and the dielectric constant of the wood. At present there are several manufacturers of resistance-type meters, and one manufacturer of power-loss type meters in the United States. No capacitance-type meter is now being marketed in this country.

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

Electrical Properties of Wood

The electrical properties of wood important for electric moisture meters are **(1)** the direct current resistance, **(2)** the dielectric power factor, and **(3)** the dielectric constant.

Electrical Resistance

The electrical resistance is the property of a piece of material that impedes the flow of electric current through the material. This requires that an electromotive force or electric potential difference exists across the material to cause a current to flow. In most cases, the magnitudes of resistance, electromotive force, and current are related by a simple proportion known as Ohm's law.

Effect of moisture content.--The direct-current resistance of wood varies greatly with moisture content below the fiber-saturation point. As the moisture content changes from the fiber-saturation point (about 30 percent moisture, based on the dry weight of the wood) to the oven-dry condition, the resistance increases by a factor of over 10 million. In this range of moisture content, a rough linear inverse relationship exists between the logarithm of the resistance and the logarithm of the moisture content. As the moisture content increases above the fiber-saturation point, the electrical resistance changes erratically but by only a small amount. Increasing the moisture content from fiber saturation to complete filling of the capillary structure of the wood with free water typically decreases the resistance by a factor of 50 or less. This is true even

though at complete saturation most species contain well over 100 percent moisture content based on the oven-dry weight of the wood. Typical values of resistance at room temperature, using a moisture meter electrode on Douglas-fir, 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.

Effect of temperature.--The electrical resistance of wood decreases as the temperature of the wood increases, although this effect is very small and possibly reversed when the wood is below about 8 percent moisture content. This is opposite to the temperature effect 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. The conduction of current by wood is thus likely to be at least in part ionic. For moisture levels above about 10 percent, the resistance of wood is roughly reduced by a factor of 2 for each increase in temperature of 10° C.

Effect of moisture gradients.--Frequently wood that is being checked for moisture content has only recently completed the drying or seasoning process and almost certainly does not have the same moisture content throughout the material. Specifically, the center of the piece will be at a higher moisture content than the surface. If the drying has occurred under reasonably constant and not too severe conditions and no part of the piece is still above fiber saturation, the moisture content at a depth of one-fourth to one-fifth of the thickness below the surface of a board will be nearly equal to the average for the entire cross section. Correspondingly, at a depth of about one-sixth of the diameter of a circular cross section, the moisture content will be about equal to the average for the cross section.

Because of the strong effect of moisture on resistance, these moisture gradients are accompanied by proportionately higher resistance gradients. This important fact makes it possible to measure moisture gradients easily, using resistance-type moisture meters equipped with electrodes that can probe the specimen at any depth.

Effect of grain angle.--The resistance of wood parallel to the grain is about half that perpendicular to the grain. Ratios of resistance perpendicular to the grain, in relation to the longitudinal value, are about 1.8 for radial and 2.0 for tangential.

Effect of chemical treatment.--The resistance of wood that has been impregnated with inorganic salts for decay or fire resistance or other purposes will generally be lower than that of untreated wood (28). The effect of salt impregnants is negligible in wood at 8 percent or lower moisture content, but rapidly becomes more important at moisture contents above 10 percent. Wood that has been in prolonged contact with sea water may also show lower than normal resistance because of the salt deposited in the wood.

Effect of species.--The resistance of wood varies somewhat between species, even when all other important factors are equal. This species difference is not great but is measurable. The source of this difference is not completely understood, but it lies, in part at least, in differences in electrolyte concentration and differences in structure that affect the available surface area within the wood.

Dielectric Properties

The most important dielectric properties of wood are the dielectric constant and the dielectric power factor.

Dielectric constant.--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 (or practically, 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.

Dielectric power factor.--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, this energy is completely recoverable when the field is removed. With practical dielectrics, however, some energy is lost in the store-recover cycle; this energy appears as heat within the dielectric material. If the fraction of the stored energy that is lost in one store-recover cycle is not unusually large, this fraction is equal to the power factor. The power factor can vary from 0 to 1. The energy lost per store-recover cycle is equal to the product of the power factor and the energy stored, and the energy stored is proportional to the dielectric constant. Therefore, the energy loss per cycle is proportional to the product of the power factor and the dielectric constant. This latter product is the dielectric loss factor.

If the dielectric is in an electric field that is oscillating at a constant frequency, the dielectric 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.

Effect of moisture content.--Both the dielectric constant and power factor increase with increasing moisture content, at least near room temperature. As the moisture content increases from 0 to about 30 percent, the dielectric constant increases along a curve that is concave upward. Above 30 percent moisture, the dielectric constant increases roughly linearly with increasing moisture (13).

In the moisture range of 0 to 30, the power factor is a rather complex function of moisture. From 0 to about 8 percent moisture, the power factor-moisture curve is concave downward; from about 8 to about 12 percent moisture, the power factor is nearly constant; and above 12 percent moisture, the power factor-moisture curve is concave upward (10). The curvatures of the relationships between dielectric constant and moisture, and between power factor and moisture, are complementary in such a way that the relationship between loss factor and moisture content is nearly linear in the range of moisture content from 0 to about 12 to 14 percent. Above 12 to 14 percent, the loss factor increases rapidly with increasing moisture content (8, 10).

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

The power factor of oven-dry 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, being the product of two quantities that increase with density, also increases with density. Limited data indicate that the relationship is roughly linear.

Effect of species and temperatures.--The dielectric properties of wood are practically independent of species with all other factors, such as density, being equal.

The variation of the dielectric properties of wood with temperature has not been studied, but it is certain that temperature would affect the dielectric properties because wood contains polar molecules.

Resistance Type of Moisture Meter

Resistance-type moisture meters are portable, battery-operated, wide-range ohmmeters. Most models have a direct reading meter, calibrated in percent for one species, and correction tables are provided for other species.

Electrode Design

To measure the electrical resistance of a wood specimen, the specimen must be arranged as an element in an electric circuit. This requires electrical contact with the wood at two points, using a method of contact that produces consistent and meaningful results.

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

Since surface contact electrodes are not satisfactory, the electrode must penetrate into the wood. The simplest electrodes of this type have poles consisting of nail-like pins that are driven into the wood. This design is entirely satisfactory and is widely used because of its simplicity. Electrodes that are screwed into the wood also are in limited use.

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

Pin-type electrodes are driven into the specimen from one side, so the measured resistance is 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. Because of the steep resistance 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 wettest wood in contact with one pole of the electrode is at a different moisture content than the wettest wood in contact with the other pole, the drier of the two will limit the current and thus be responsible for the reading. Thus, it is important to emphasize that the reading of a resistance-type moisture meter will be related to the wettest wood that contacts both poles of the electrode.

Resistance data for calibrating resistance-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.

Standard four-Din electrode.--The most common moisture meter electrode uses four steel phonograph needles that extend about five-sixteenths inch beyond their mounting chucks. Each pole of the electrode uses two of the phonograph needles or pins. The poles are about 1 to 1-1/2 inches apart and the two pins comprising each pole are about one-half inch apart. The structure of the electrode is a plastic material combining good mechanical strength and high electrical insulating value. A handle is attached for driving and extracting the electrode. The pinlength of five-sixteenths inch is about one-fifth of the thickness of nominal 2-inch dimension lumber (actual thickness 1-5/8 inches), so

it 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.

This electrode, along with an insulated two-pin electrode and two typical resistance-type meters, is illustrated in figure 1.

Long two-pin electrodes.--Measuring the average moisture content of material thicker than 2 inches requires a pin longer than five-sixteenths inch. Most meter manufacturers fill this need with an electrode with two pins, each comprising one pole of the electrode and about 1 inch long. To achieve the necessary strength, these longer pins are larger in diameter than the 5/16-inch-long pins. Two instead of four pins are used to permit the larger pins to be driven and extracted more easily.

Despite the larger diameter and consequent larger contact area of the pins used in two-pin electrodes, readings using this electrode are consistently lower, by about 1/2 to 1 percent, than readings using the four-pin electrode (8). Apparently, doubling the contact area of a single pin is substantially less effective in reducing the net resistance than is 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.

At least one manufacturer of resistance-type moisture meters offers a two-pin electrode with pins about 3 inches long for use on poles, bridge timbers, and other large material .

Insulated-pin electrodes.--Some manufacturers offer electrodes with 1- or 3-inch pins that are covered by a tough insulating resin except at the tip. These electrodes are useful when testing lumber that has a high superficial moisture content, such as is caused by rain or dew. Such superficial films of high moisture are rarely detrimental to the usefulness of the lumber. With uninsulated pin electrodes, however, a resistance-type moisture meter would indicate these high surface moisture contents and could result in the lumber being rejected. Using insulated pins driven to the proper depth, the true average moisture content may be measured.

Even insulated pins cannot be used successfully on lumber with free water on the surface because the water will follow the pins as they penetrate the wood, giving a very high, misleading moisture reading.

Veneer electrodes.--For using a resistance-type meter on veneer, an electrode is supplied that consists of a large number of needles about one-eighth inch long, which are arranged into two groups; each group is one pole of the electrode.

Substitute electrodes.--When either the average or the core moisture content of a specimen with large cross section must be measured and the pins of the available electrodes are too short, two nails may be used 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.

Useful Range of Resistance-Type Meters

The useful range of resistance-type moisture meters is from about 7 to about 30 percent moisture content, and only approximate qualitative readings may be obtained on wood with over 30 percent moisture content.

Radio-Frequency Type of Moisture Meter

The two principal types of radio-frequency moisture meter are the capacitance type and the power-loss type. No portable model of the capacitance type is currently being manufactured in the United States. The power-loss type is occasionally referred to in the trade as the "capacity-type" meter.

Capacitance type.--Moisture meters that use the relationship between moisture content and dielectric constant are called capacitance type. The wood specimen is penetrated by the electric field associated with the capacitor of the frequency-determining circuit of a radio-frequency 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. Due to technical problems and high cost, this type of meter is not at present being manufactured commercially.

Radio-frequency power-loss type.--Moisture meters that use the relation between moisture content and loss factor are called power-loss type meters. With these meters, the wood specimen is penetrated by the electric field radiating from an electrode that is coupled to a low power radio-frequency oscillator inside the meter. The amplitude of

oscillation is indicated by a microammeter that measures the grid current of the oscillator tube.

When the wood absorbs power from the radio-frequency field, the load, which depends upon the loss factor of the specimen, is reflected to the oscillator, and reduces the amplitude of oscillation. This results in reduced grid current, and is indicated by the grid current meter.

Because of the correlation between moisture and loss factor, the grid current meter may be calibrated in percent moisture content. Because of the effect of density on loss factor, however, it is apparent that a different calibration scale is required for each density increment. In practice, this requirement is fulfilled approximately by a species correction; that is, the calibration is empirically related to the average density of a given species.

A power-loss type moisture meter is illustrated in figure 2.

Automatic moisture meter.--A radio-frequency meter is currently available that continuously monitors the moisture content of material moving along a conveyor and automatically marks or ejects material with improper moisture content. This meter is reported by the manufacturer to operate on a combination of the capacitance and resistance principles (7). A typical installation of this meter is shown in figure 3.

Electrodes

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

For rough lumber.--This electrode consists of a number of short, spring-loaded rods with the exposed ends rounded, mounted in a circular plastic plate about 3 inches 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. Due to 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 this electrode consists of a single spring-loaded metal disk, slightly over 1 inch in diameter, surrounded by a circle of smaller but similarly spring-loaded metal disks. This arrangement is mounted on a plastic plate about 3-1/2 inches in diameter.

The electric field from these electrodes penetrates about three-fourths inch into the specimen, so that specimen thicknesses up to about 1-1/2 inches may be used. With any surface contact electrode for radio-frequency meters, however, the surface layers of the specimen have a predominant effect on the meter readings, simply because the electric field is stronger near the electrode.

For smooth surfaces.--An electrode that gives slightly higher precision, but is usable only on smooth, plane surfaces is the quadrant type. This consists of the four quadrants of a 3-inch disk, separated slightly and independently free to move slightly, mounted on a plastic plate. The field of penetration of this electrode is about 3/4 to 1 inch.

For veneer.--This electrode consists of several concentric rings, all in one plane, mounted on a plastic plate about 3 inches in diameter. The field penetration of this electrode is about one-eighth inch. When measuring the moisture content of material thinner than one-eighth inch with this electrode, it may be important to consider the material on the other side of the specimen. If this backup material is metal or a high loss dielectric, the reading of the moisture meter probably will be grossly in error. It is best to use a low loss backup material, such as glass or polystyrene.

For thick specimens.--This electrode consists of a ring of spring-loaded metallic disks surrounding a somewhat larger single disk in the center. It is similar to the electrode described earlier for rough lumber. The thick specimen electrode differs only in that it is scaled up in size, so the field penetrates about 2 inches.

Useful Range of Radio-Frequency Meters

The useful range of available power-loss meters is from 0 to about 25 percent moisture content.

Factors That Affect the Accuracy of Moisture Meters

In no situation is the accuracy of an electric moisture meter, in good working condition, limited by the ability of the instrument to measure the fundamental quantity on which the calibration is based. In short, resistance-type meters are capable of measuring resistance with very small error. The readings of radio-frequency meters are closely and reproducibly related to the loss factor or dielectric constant of the specimen. The accuracy of these instruments as moisture meters is limited only by the correlation between moisture content and the particular electrical property being measured.

Generally, the electrical properties of wood are fairly precise functions of moisture content only within the moisture range from zero to fiber saturation. The precision decreases as the moisture content approaches fiber saturation. This fact limits the useful range of electric moisture meters to moisture levels below fiber saturation, although approximate qualitative readings may be obtained above fiber saturation with a resistance meter.

The low moisture limit of the range of electric moisture meters is zero for radio-frequency types although the sensitivity, and thus the precision, of these meters is low when the wood is very dry. The low limit for resistance-type meters is about 6 or 7 percent, because at moisture levels lower than this the resistance values are too high to measure with a simple portable instrument.

The accuracy of individual readings of electric moisture meters cannot be specified precisely because numerous unknown factors introduce variability into the readings. When properly used to determine the average moisture content of a large lot of lumber that has a reasonably uniform distribution of moisture, the meter determination should be within 1 percent moisture content of the true average (11).

Limited data indicate that, when using a resistance-type meter on wood at less than 25 percent moisture content, the probable error is approximately 0.5 percent moisture content. Consequently, half of any reasonably large number of readings on a sample of similar specimens will be within 0.5 percent moisture of the true value, and less than 5 percent of the readings will be more than 2 percent from the true reading. The variability does appear to depend on species, however, and as a result individual errors may be two or three times these values.

At higher moisture levels, the variability increases. At 30 percent moisture, roughly one-tenth of the readings on a fairly uniform sample will be in error by more than 5 percent moisture, and at 40 percent moisture content roughly one-tenth of the readings will be in error by 8 percent or more.

Corresponding data for power-loss-type meters indicate that for moisture levels between 7 and 12 percent, the probable error is usually between 0.5 and 1 percent. Thus, less than half of a given set of readings on a reasonably uniform sample will be in error by 1 percent or more, and fewer than 5 percent of the readings will be in error by 3 percent or more. At between 12 and 25 percent moisture, the probable error increases with increasing moisture until at 25 percent moisture the probable error is roughly 1 to 2 percent. On this basis, less than half of a given set of readings will be in error by more than 2 percent, and fewer than 5 percent of the readings will be in error by 6 percent or more.

It should be emphasized that these estimates are based on limited data, and serve only to illustrate the general order of the expected errors. With reasonably large samples, these errors would be approximately normally distributed, so that the sample mean would still be expected to approximate the mean of the lot sampled to within ± 1 percent, provided proper calibration and corrections were used.

The principal factors other than moisture that affect the readings of electric moisture meters are: (1) Species, (2) specimen density, (3) moisture distribution, (4) specimen thickness, (5) temperature, (6) electrode contact, (7) grain direction, (8) chemicals in the wood, (9) weather conditions, (10) adequacy of sample, and (11) care or skill of operator.

Species

At a given moisture content, both the resistance and dielectric properties of wood depend on species. The primary basis for this dependence is probably because species differ in structure and electrolyte concentration in the case of resistance, and differ in density in the case of dielectric properties. Because of the effect of species, species corrections should be made when the data are available.

If species correction data are not available, resistance meters may be used for approximate readings, because the species corrections are usually less than 2 percent, especially when below 15 percent actual moisture content. Power-loss meters may also be used by applying the corrections for a species of density similar to that of the specimens to be tested, but the results are reliable only as rough approximations.

Specimen Density

The readings of resistance meters are practically independent of specimen density. The readings of radio-frequency meters, however, are affected by the density of the specimen material. A substantial part, at least, of the species corrections for radio-frequency meters is actually a density correction. The species correction must, of course, be related to the average density of the species, and any single moisture determination will then be in error by an amount related to the deviation of the density of the specimen from the average for its species (or more precisely, the average of the sample used for calibration of the meter). The American firm manufacturing power-loss meters provides two species corrections for some widely used species, one for high-density specimens and one for low-density. Even if specimen density could be determined easily and reasonably accurately, however, available information is inadequate to permit a general density correction to be made.

Moisture Distribution

High surface moisture, such as from rain or dew, forms a surface layer of low resistance and high dielectric constant and loss factor. This superficial moisture would in general cause electric moisture meters of any type to read much too high.

The average moisture content of a specimen with high superficial moisture may be read using a resistance-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 not be made nearer than 15 to 20 inches from the end, or one-half the length of the specimen, whichever is smaller.

Moisture gradients in wood that is drying may differ greatly from the expected form, causing readings of resistance meters at one-fourth to one-fifth of the thickness to differ greatly from the average moisture content of the cross section. This situation may be observed 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 near the center, suggests that the one-fourth to one-fifth thickness rule cannot be used.

Irregular drying gradients have only minor effects on the readings of radio-frequency meters, as the reading is the integrated effect of all the specimen material penetrated by the field. The material nearest the electrode does have a predominant effect however, and in extreme cases (such as wet surfaces mentioned earlier) the reading could differ greatly from the average moisture content.

Specimen Thickness

The problem of specimen thickness is related to the problem of moisture distribution or gradient. If the specimen had a uniform moisture content, its thickness would not be a factor in the accuracy of the meter reading. With normal moisture gradients during drying, however, it is necessary to relate the thickness of the specimen to the depth at which the meter reads in order for the meter reading to be a valid estimate of the average moisture content.

Thus, it is necessary for the pins of resistance meter electrodes to be long enough to reach one-fifth to one-fourth of the thickness, and the field from radio-frequency meter electrodes should penetrate roughly to the middle of the specimen. With both types of instrument, the electrode should be selected to match the specimen thickness.

Temperature of the Specimen

As the temperature of wood increases, its electrical resistance decreases and vice versa (2, 9). The rate of change of resistance with temperature increases as the moisture content increases, and is quite small at moisture levels below 6 to 8 percent. The effect of temperature is generally enough that temperature corrections should be made when using a resistance-type meter on specimens that are warmer than 90° F. or cooler than 70° F. The amount of correction depends both on the temperature and moisture content, so it is best to determine the correction from a chart such as figure 4. If a chart is not available, a rough correction is to subtract 1 percent moisture content from the reading for every 20° F. the specimen temperature is above the calibration temperature (usually 80° F.) and add 1 percent for every 20° F. the specimen temperature is below the calibration temperature.

Data on the effect of temperature on the dielectric loss factor and dielectric constant of wood are not available, so temperature corrections cannot be specified for radio-frequency meters.

Electrode Contact

It is important for accurate readings that the electrode pins be driven to their proper depth into sound wood when using a resistance meter, and that the surface electrodes of radio-frequency meters be pressed firmly against the specimen. When a radio-frequency meter is used, the specimen should cover the electrode with an amount to spare on all sides at least equal to the specimen thickness.

Grain Direction

Grain direction has no effect on the readings of radio-frequency meters, because the electrodes are symmetrical. With resistance meters, however, the electrode should be oriented so the current flows parallel to the grain whenever possible. 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 moisture content lower than readings parallel to the grain.

Chemical Treatments, Glues, and Finishes

Wood that has been treated with salts for preservative or fire retarding purposes will generally have lower resistance and higher dielectric constant and loss factor than untreated wood at the same moisture content. Consequently, electric moisture meter readings on wood so treated will generally be too high. The error increases with increasing moisture content, and is usually negligible when the wood is below about 8 percent moisture content. At moisture levels above 10 to 15 percent, the error becomes larger rapidly and erratically, making correction impossible. Oil-borne organic preservatives, such as creosote and pentachlorophenol, do not significantly affect the readings of electric moisture meters (28).

Some types of glue used in plywood are electrical conductors, and may therefore affect the readings of electric moisture meters (1). The effect of plywood glue lines on the reading of a resistance meter may be determined by observing the meter reading as the electrode pins are driven into and then through the first ply. If the meter shows an abrupt increase in reading as the pins contact the glue line, moisture 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 resistance meter with insulated pins. The conductivity of the finish may be checked by just pricking the finish with resistance electrode pins; a high moisture reading would then indicate a conductive finish, and no reading would indicate a nonconductive finish.

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.

Adequacy of Sample

The number of specimens in the sample is an important factor affecting the accuracy of electric moisture meters, but at the same time it is difficult to specify. The question of adequate samples arises because of the typical variability in moisture determinations made with electric moisture meters. This variability is in addition to the variability in actual moisture content within a given lot of lumber, and is due to variability in the relationship between electrical properties and moisture content in wood.

If the sample is a single board, it should be checked at three locations in order to minimize errors from uneven length and width distribution of moisture. If a lot is to be checked, a certain fraction of the lot should be used as a sample, the fraction depending on the size of the lot. Experience and logical considerations suggest that a minimum sample should be 10 percent of a large lot if a resistance meter is used and 20 percent of a lot if a radio-frequency meter is used. The sample should be drawn at random, so that every board in the lot has an equal chance of being in the sample. With lots of fewer than 100 boards, the fraction in the sample should be increased so that no sample is fewer than 10 specimens (or the entire lot, whichever is smaller) if a resistance meter is used, or 20 specimens if a radio-frequency meter is used.

Skill of Operator

Electric moisture meters are relatively easy to operate, and nearly anyone can learn to use them properly. The accuracy and reliability of the readings, however, does depend on the care exercised by the operator. Important points here are careful adjustment of the meter controls, proper application of necessary correction factors, insuring proper application of the electrode, attention to the condition of the instrument, and, of course, the obvious importance of reading the meter correctly.

Maintenance

The principal item of maintenance is replacement of defective or exhausted components of the instrument. Recalibration is rarely needed, especially with resistance meters, but the calibrations should be checked periodically using standards that are supplied by the meter manufacturers.

Replacements and Repairs

Most electric moisture meters are powered by self-contained dry batteries. These batteries commonly will power the meter adequately for 6 months to a year of 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.

Vacuum tubes in moisture meters are operated far below their rated power, and will normally give years of service. Occasional replacements will be required, however.

Electronic components other than tubes and batteries may occasionally fail. These should be replaced only by a competent technician.

The pins of resistance meter electrodes necessarily receive hard usage, and it is not uncommon for them to be bent or broken in use. It is always 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 instrument should in general be handled carefully, as excessive rough handling can damage such fragile components as the meter movement or vacuum tubes.

Makers and Dealers of Electric Moisture Meters⁴

<u>Makers and dealers</u>	<u>Trade name</u>	<u>Type</u>
Boonton Polytechnic Co., Inc. Boonton, N. J,	Model HFR-4E ⁵	Radio-frequency power-loss
Coe Manufacturing Co. Painesville, Ohio	Laucks Sentry ⁶	Resistance-capacitance combination

⁴

This list has been prepared for the information of correspondents. The inclusion of names in the list implies no endorsement of the product by the Forest Products Laboratory.

⁵

A nonportable laboratory instrument.

⁶

An automatic machine for checking moisture content of moving lumber, veneer, or paper.

<u>Makers and dealers</u>	<u>Trade name</u>	<u>Type</u>
A.M. Conway and Son 1623 Sixth Avenue, SE. Portland 14, Oreg.	Laucks Sentry ⁶	Resistance- capacitance combination
Delmhorst Instrument Co. 607 Cedar Street Boonton, N. J.	Delmhorst Moisture Detector	Resistance
Garden City Instruments, Inc. 931 Sherman Avenue Evanston, Ill.	Weston (Tag-Heppen- stall) Moisture Meter	Resistance
Hart - Moisture-Meters, Inc. 336 West Islip Boulevard Babylon, N. Y.	Hart Moisture Meter	Resistance
Industrial Instruments, Inc. 156 Culver Avenue Jersey City, N. J.	Megohm Bridge	Resistance
Kel Engineering-Equipment Co. 11 Cambridge Lane New Brunswick, N. J.	Kett Wood Moisture Meter	Resistance
Laucks Laboratories, Inc. Overlake Park Bellevue, Wash.	Laucks Sentry ⁶	Resistance-capacitance combination
C. M. Lovsted and Co. 4000 Iowa and Marginal Way Seattle, Wash	Tag-Heppenstall and Moisture Register ⁷	Resistance Radio-frequency power-loss
Moisture Register 1510 West Chestnut Street Alhambra, Calif.	Moisture Register ⁷	Radio-frequency, power-loss, and resistance

⁷

Both a resistance-type and a radio-frequency-type meter are made with the trade name of Moisture Register."

<u>Makers and dealers</u>	<u>Trade name</u>	<u>Type</u>
Moore Dry Kiln Co. P.O. Box 4248 Jacksonville 1, Fla. also North Portland, Oreg.	Moore Kiln-Eye ⁸ Moore Moisture Meter Delmhorst Moisture Detector	Resistance
National Engineering Co. P.O. Box 1475 Indianapolis 6, Ind.	Tag- Heppenstall Moisture Meter ⁷ Moisture Register ⁷	Resistance Radio-frequency, power-loss, and resistance
Physics Research Labora- tories, Inc. 507 Hempstead Turnpike West Hempstead, N. Y.	Gann Hydromat	Resistance
Standard Dry Kiln Co. Indianapolis 6, Ind.	Moisture Register ⁷	Radio-frequency, power-loss, and resistance
Thwing-Albert Instrument Co. Penn Street and Pulaski Ave. Philadelphia 44, Pa.	Thwing- Albert Electronic Moisture Meter	Resistance
W. von Arnould Co. 95 Grove Street Oakland, N. J.	Hydromette H ⁹ Gann	Resistance
Weston Electrical Instrument corp. 614 Frelinghuysen Avenue Newark, N. J.	Weston Moisture Meter	Resistance
George E. Zweifel 1123 Gilson Street, NW. Portland, Oreg.	Moisture Register ⁷	Radio-frequency, power-loss, and resistance

⁸ A remote reading resistance-type meter for checking moisture content of kiln samples.

⁹ A vest-pocket-size instrument made in Germany.

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Table 1.--The average electrical resistance along the grain in megohms, measured at 80°F. between two pairs of needle electrodes 1-1/4 inches apart and driven to a depth of 5/16 inch, of several species of wood at different values of moisture content.

Species of wood	Moisture content in percent																		
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Conifers:																			
Baldypress.....	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	0.79	0.60	0.46
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	0.83	0.63
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	0.86	0.62
Hemlock, eastern.....	120,000	20,000	4,300	1,300	450	200	100	45	45.0	25.0	14.0	8.8	5.40	3.50	2.30	1.60	1.10	0.78	0.57
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	0.72	0.51	0.37
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	0.87	0.66
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	0.98
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	0.79	0.60
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	0.91	0.67
Pine, white.....	20,900	5,620	2,090	830	405	200	102	58	33.1	19.9	12.3	7.9	5.01	3.31	2.19	1.51	1.05	0.74	0.52
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	0.87	0.69
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	0.93	0.66
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	0.75	0.56
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	0.85	0.71	0.60
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	0.91	0.71
Hardwoods:																			
Ash, black.....	14,000	2,300	600	200	85	40	20	10	6.0	3.4	2.1	1.3	0.90	0.60	0.42	0.32	0.25	0.20	0.17
Ash, white.....	12,000	2,190	690	250	105	55	28	14	8.3	5.0	3.2	2.0	1.32	0.89	0.63	0.50	0.44	0.40	0.40
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	0.88	0.61	0.43	0.33	0.26
Basswood.....	36,300	1,740	470	180	85	45	27	16	9.6	6.2	4.1	2.8	1.86	1.32	0.93	0.69	0.51	0.39	0.31
Birch.....	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	0.95	0.70
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	0.81	0.59	0.43
Elm, American.....	18,200	2,000	350	110	45	20	12	7	3.9	2.3	1.5	1.0	0.66	0.48	0.42	0.40	0.40	0.40	0.40
Hickory.....	31,600	2,190	340	115	50	21	11	6.3	3.7	2.3	1.5	1.0	1.00	0.71	0.52	0.44	0.40	0.40	0.40
Khaya.....	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.....	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	0.74	0.50	0.32
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	0.72	0.49	0.35	0.26
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	0.98	0.75	0.60
Oak, northern red.....	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	0.95	0.80	0.63	0.50
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	0.79	0.60	0.49	0.44	0.41
Philippine mahogany (Shorea spp.).....	2,890	690	220	80	35	15	9	5	2.8	1.7	1.1	0.7	0.45	0.30	0.21	0.16	0.12	0.09	0.07
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	0.87	0.63	0.46
Tupelo, black.....	31,700	12,600	5,020	1,820	725	275	120	58	27.6	13.0	6.9	3.7	2.19	1.38	0.95	0.63	0.46	0.33	0.25
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	0.72	0.51	0.38
Yellow-poplar.....	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	0.85

¹Exact species unknown.

²Known in the trade as "African mahogany."

³The values for this species were calculated from measurements on veneer.

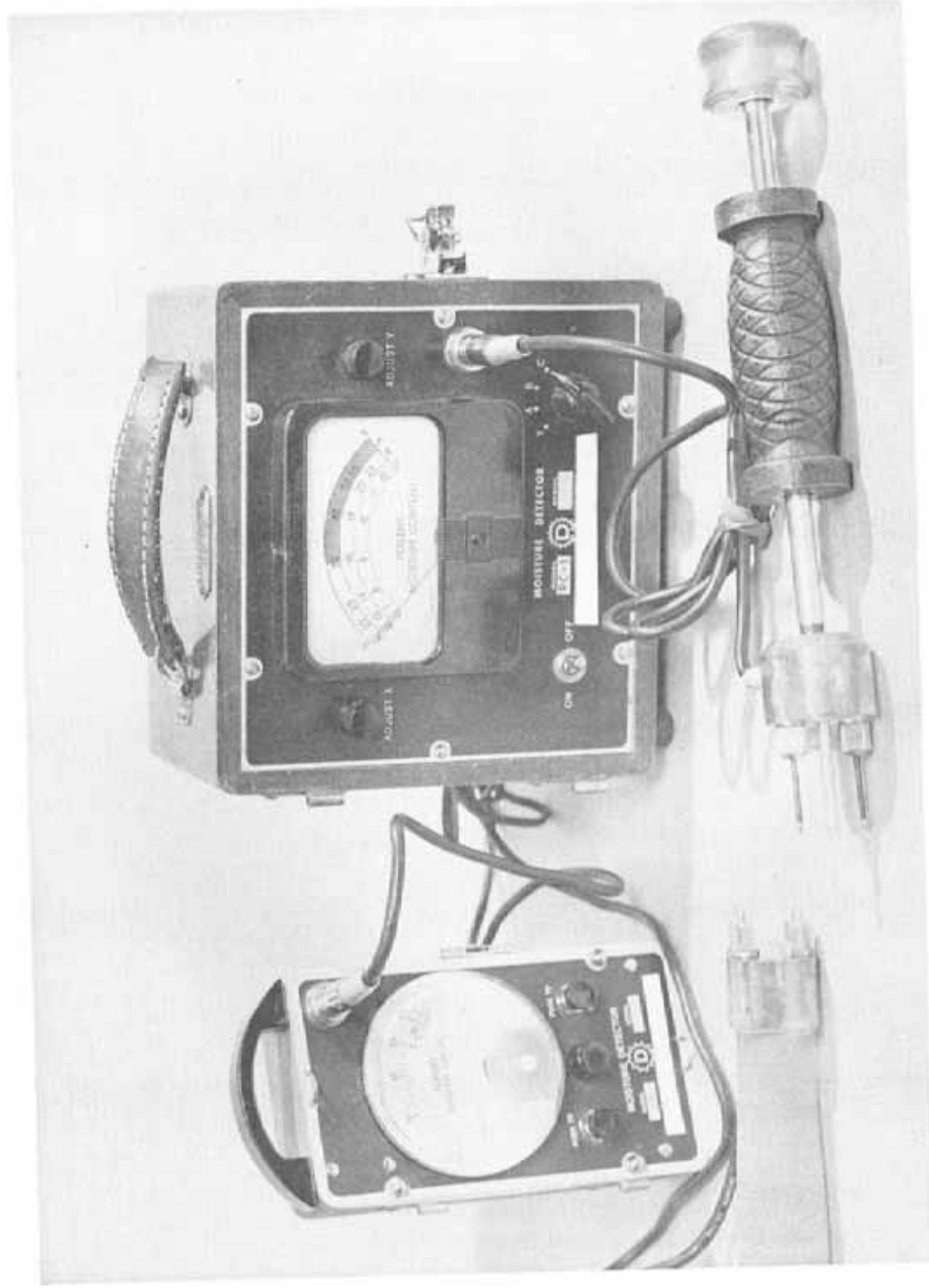


Figure 1. --Resistance-type moisture meter.

ZM 117 486



Figure 2. --Radio-frequency power-loss type moisture meter.

ZM 118 516

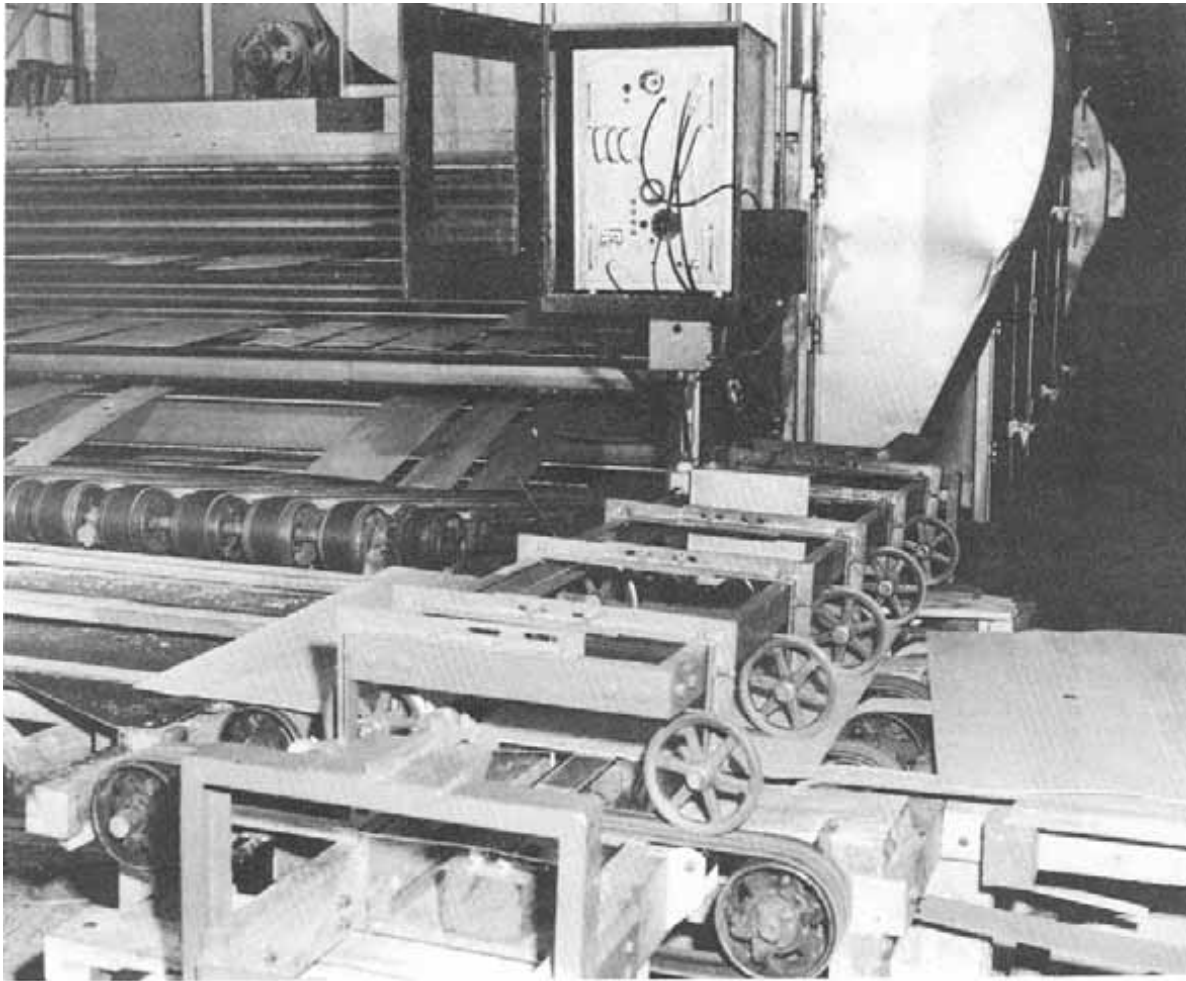


Figure 3. --Typical installation of a machine used to measure the moisture content of moving lumber, veneer, or paper.

ZM 96878 F

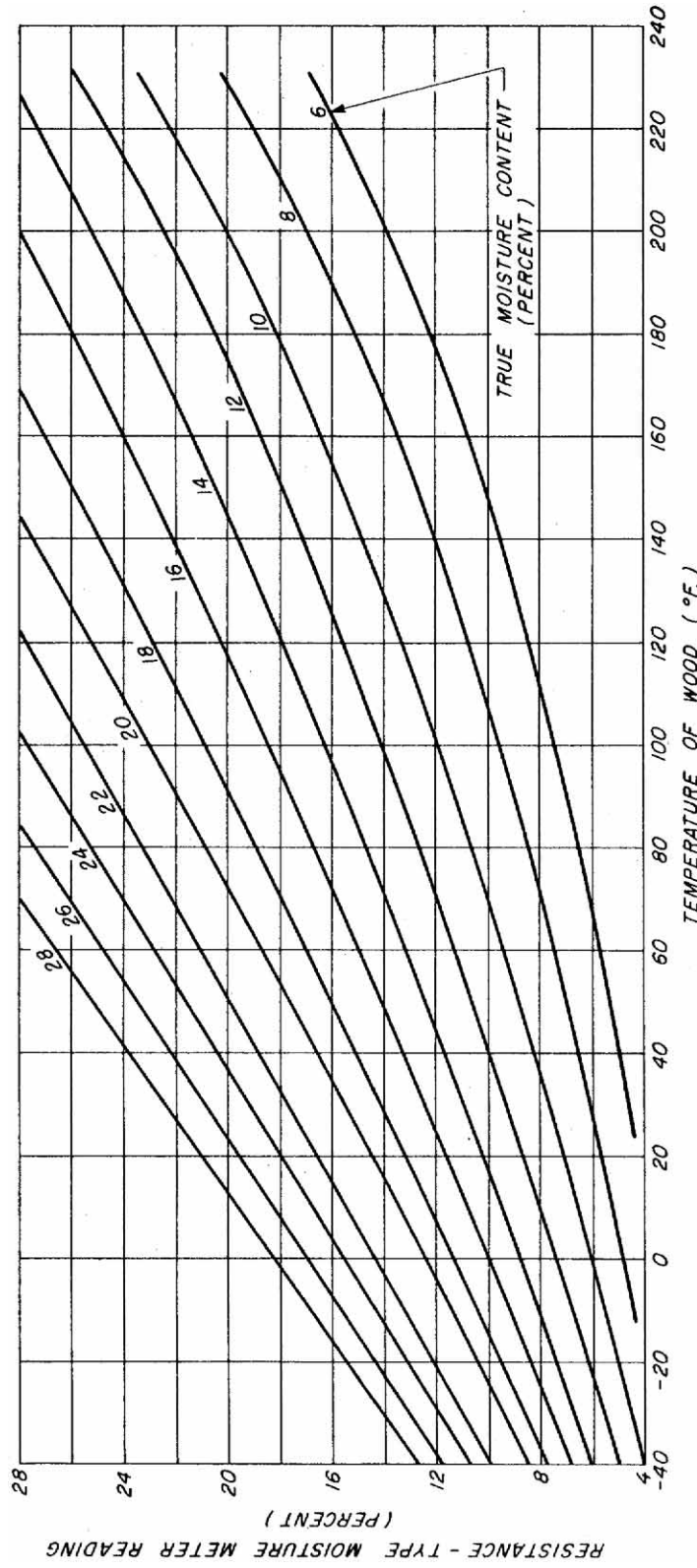


Figure 4. --Temperature corrections for reading of resistance-type moisture meters, based on combined data from several investigators. Find meter reading on vertical left margin, follow horizontally to vertical line corresponding to the temperature of the wood, interpolate true moisture from family of curves. Example: if meter indicated 18 percent on wood at 120° F., true moisture content 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 be obtained simply by shifting the temperature scale so that the true calibration temperature coincides with 70° on the percent scale. For example, for meters calibrated at 80° F., add 10° to each point on the temperature scale (shift the scale 10" toward the left), and use the chart as before.

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